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B. T. GALLOWAY, *Chief of Bureau.*

NATURAL VEGETATION AS AN INDICATOR OF THE CAPABILITIES OF LAND FOR CROP PRODUCTION IN THE GREAT PLAINS AREA.

BY

H. L. SHANTZ,

PHYSIOLOGIST, ALKALI AND DROUGHT RESISTANT PLANT BREEDING INVESTIGATIONS.

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BUREAU OF PLANT INDUSTRY.

Chief of Bureau, BEVERLY T. GALLOWAY.
Assistant Chief of Bureau, WILLIAM A. TAYLOR.
Editor, J. E. ROCKWELL.
Chief Clerk, JAMES E. JONES.

ALKALI AND DROUGHT RESISTANT PLANT BREEDING INVESTIGATIONS.

Thomas H. Kearney, *Physiologist in Charge.*
H. L. Shantz, *Plant Physiologist.*
A. C. Dillman, *Assistant Plant Physiologist.*

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Plant Industry,
Office of the Chief,
Washington, D. C., October 11, 1910.

Sir: I have the honor to transmit herewith and to recommend for publication as Bulletin No. 201 of this Bureau the accompanying manuscript entitled "Natural Vegetation as an Indicator of the Capabilities of Land for Crop Production in the Great Plains Area," by Dr. H. L. Shantz, Physiologist, Alkali and Drought Resistant Plant Breeding Investigations, Bureau of Plant Industry.

Extensive tracts of land, including thousands of acres that are doubtless capable of producing crops, still remain unoccupied in the United States, especially west of the ninety-eighth meridian. In places where no attempts at tillage have yet been made the would-be settler or investor is often at a loss to know whether the land in view is adapted to a particular crop or even whether it has any agricultural value. In such places the character of the natural vegetation is usually studied as an index of its crop-producing possibilities, but mistakes are often made in using this indicator without sufficient consideration.

The object of the present paper is to show how the native plant cover can safely be used as a guide to probable crop production. As a result of investigations carried on during the past three years in the Great Plains area definite correlations have been determined between the different types of vegetation and the physical characteristics and crop possibilities of the land occupied by each type. Although most of the detailed investigations have been carried on in eastern Colorado, enough work has been done elsewhere to show that with comparatively little modification the results can be applied throughout the Great Plains area. When the correlations are worked out for a given region as carefully as has been done in the present instance, they should not only be useful as a means to land classification on a large scale, but they could be applied by farmers and other persons who have occasion to estimate the probable agricultural value of new land.

The author desires to acknowledge his indebtedness to Dr. L. J. Briggs, Physicist in Charge of the Physical Laboratory of the Bureau of Plant Industry, for much advice and assistance in the physical part of the investigations. In connection with the experimental work in the field Mr. E. C. Chilcott, Agriculturist in Charge of Dry-Land Agriculture Investigations, Bureau of Plant Industry, placed at the author's disposal the resources of the dry-land experiment farms in the Great Plains area. The Bureau of Soils has obligingly furnished chemical and mechanical analyses of numerous soil samples.

Respectfully,

G. Harold Powell,
Acting Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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NATURAL VEGETATION AS AN INDICATOR OF THE CAPABILITIES OF LAND FOR CROP PRODUCTION IN THE GREAT PLAINS AREA.

INTRODUCTION.

Farmers and other persons who have occasion to examine new land in order to form a judgment of its agricultural value depend largely upon the natural vegetation, or plant covering, as an indicator of its crop-producing capabilities. But there are many possibilities of error in judging land upon this basis. Species that are closely related botanically and very similar in appearance may indicate quite different conditions of soil and climate. The popular names of plants are likely to cause confusion. Thus, the farmer who has learned in the Great Basin region that "greasewood" is an indicator of alkali land and that "sage brush" usually grows on land free from alkali will find, if he moves to southern Arizona or southeastern California, that the shrub there known as "greasewood" indicates absence of alkali, while the so-called "sage bushes" of that region grow on strongly alkali land. Furthermore, there is a general tendency to depend upon a single plant species as an indicator, while the investigations set forth in this bulletin show that the composition of the plant covering as a whole is a much more reliable basis for judging the crop-producing capabilities of land.

The chief object of the present paper is to show how these sources of error may be avoided and how new land may be classified readily and with reasonable accuracy on the basis of its natural vegetation. This paper is not a report of a land survey, but rather a discussion of methods which it is believed could be utilized to advantage in making such a survey, the methods being illustrated by application to a limited territory in the Great Plains area.

Too much emphasis can not be laid upon certain facts that have been clearly brought out in the course of these investigations: (1) Correlations between the natural plant cover and the crop-producing capabilities of land in a given area can be satisfactorily determined only after careful study of the different types of vegetation of the area in relation to their physical environments; (2) such correlations,

determined for some particular region, will need to be modified to a greater or less extent before they can be applied in another region where the physical conditions are different. When, as a result of sufficient investigation, correlations of this nature are determined for a given area, it is believed that they will afford a basis for classifying the land of that area more readily and at least as accurately as by any other known method.

In order to test and perfect the methods here described it was necessary to make a detailed study of the vegetation of some particular area in relation to the physical conditions, checking the observations by the study of such examples of actual crop production as exist on the different types of land. It was decided to begin work in the Great Plains area that lies between the ninety-eighth meridian and the Rocky Mountains, for this region contains the largest body of land in the United States having possible agricultural value on which the native plant covering is still undisturbed. A further advantage is the comparative uniformity of the climate throughout the area from the Canadian boundary on the north to the "Panhandle" of Texas on the south. The investigations thus far have been made chiefly in a portion of eastern Colorado, a region which is considered representative because of its central position and because its climatic conditions are almost as extreme as anywhere in the Great Plains. But enough data have been gathered in other portions of the Great Plains to make it fairly certain that with comparatively little modification the correlations shown will hold good throughout the area.

The work so far accomplished has brought out clearly that in this area the general conditions, whether favorable or unfavorable to crop production, are indicated by the character of the native plant cover. Land which bears a pure short-grass cover was found to be supplied with water in the surface foot or two of soil only, and usually even to that depth for but a brief period during spring and early summer. Land with a uniform cover of tall grasses was found to be supplied with water to a much greater depth and to offer conditions favorable for plant growth during a much longer season. As a connecting link between these two conditions a short-grass cover which supports a scattered growth of taller plants was found to indicate intermediate conditions as regards water supply.

The areas of greatest agricultural value one year with another are those marked by the presence of the wire-grass vegetation (p. 48). Of almost equal value are the areas characterized by those phases of the grama–buffalo-grass vegetation which are distinguished by the presence of a considerable quantity of Psoralea (p. 46) or of wire-grass (p. 47). Bunch-grass land (p. 54) is best for crops during especially

dry years, but is relatively the least productive during favorable years. Typical short-grass land (grama–buffalo-grass association p. 24) produces more than any other type during wet years, but is first to fail in time of drought. Areas characterized by certain other types of vegetation (p. 60) were found to be unfit for agricultural purposes.

GENERAL CONSIDERATIONS ON THE USE OF VEGETATION AS AN INDICATOR.

DIFFICULTY OF CORRELATING VEGETATION WITH ANY SINGLE FACTOR OF THE ENVIRONMENT.

The great difficulty of correlating vegetation with any single factor is shown by the vast difference of opinion among botanists as to which factors are of the greatest importance in controlling plant distribution.

Correlations with the physical or the chemical nature of the soil have often been successfully applied for a limited area, but without exception these correlations have failed to apply when extended to wider areas. The results of numerous attempts seem to prove that a strict correlation of vegetation with the physical or chemical nature of the soil is possible only when all other conditions of the habitat are comparatively uniform. When the climatic conditions and the physical condition (texture, water content, etc.) of the soil are uniform we should be able to correlate variation in the vegetation with differences in the chemical nature of the soil; on the other hand, when the climatic conditions and the chemical composition of the soil are uniform, the differences observed in the vegetation are probably due to inequalities in the physical nature of the soil. Variations, either physical or chemical, are of greatest importance when they approach the limit of favorable conditions. A correlation between vegetation and either the chemical or physical nature of the soil can be expected to apply only over a limited area where the other conditions are practically uniform. As soon as we move from one region to another the correlation between vegetation and soil type is at once broken down.[a] In the Great Plains region this is very clearly brought out by the following examples:

In eastern Colorado short-grass vegetation is correlated with a loam soil, wire-grass with sandy loam soil, and bunch-grass with sand soil. Here, under conditions of practically uniform rainfall, evaporation, etc., we have a close correlation between the vegetation and the soil types.

[a] Thurmann, Julius. Essai de Phytostatique, 1849, p. 403. Warming, Eugenius. Ecology of Plants, 1909, pp. 69–70.

Again, in eastern Colorado, with a rainfall of from 15 to 18 inches, loam soil is covered with a comparatively pure short-grass cover; in west-central Kansas, with a rainfall of from 22 to 24 inches, loam soil is characterized by wire-grass vegetation; while in eastern Kansas, with a rainfall of from 26 to 30 inches, bunch-grass occurs on this type of soil. Here, under comparatively uniform soil conditions, a rather close correlation can be established between rainfall and vegetation.

But under practically uniform soil conditions the pure short-grass formation is found in the "Panhandle" of Texas, where the average annual rainfall is about 21 inches, and in eastern Colorado, with an average annual rainfall of 17 inches, while in Montana a comparable type of pure short-grass vegetation is found where the average annual rainfall is only 14 inches. Similar observations could be made upon any other type of vegetation which extends throughout the region. A correlation with amount of rainfall alone is not possible; for, if we judge from the vegetation, a rainfall of 14 inches in Montana is equivalent to a rainfall of 21 inches in Texas. Lines drawn from north to south showing conditions equally favorable for plant growth, as we pass southward, cross lines of increasingly higher annual rainfall. It is clear in this case that factors other than the amount of annual rainfall must enter into the correlation,[a] since on a uniform soil differences in the amount of annual rainfall produce no changes in the type of vegetation.

To attempt a close correlation of plant associations with temperature alone is equally difficult. The short-grass and prairie-grass formations each range from the Lower Austral through the Upper Austral and into the Transitional life zone, taking these life zones as defined by Merriam.[b] It is obvious that in the region here considered water is the chief limiting factor and temperature is of comparatively minor importance in influencing plant distribution.

From the cases above mentioned we can see that neither the rainfall nor the soil type alone determines what type of vegetation will be found in any given area; for of the first two correlations discussed in which only these factors are primarily concerned, either may be cited to disprove the other. Many similar examples could be given, but these will serve to show how utterly impossible it is to

[a] See Powell, J. W., "Lands of the Arid Region," 1879, p. 51, and Johnson, W. D., "The High Plains and Their Utilization," Twenty-First Annual Report of the United States Geological Survey, pt. 4, 1901, p. 678; also Briggs, L. J., and Belz, J. O., "Dry Farming in Relation to Rainfall and Evaporation," Bulletin 188, Bureau of Plant Industry, United States Department of Agriculture, 1910, pp. 20–22.

[b] Merriam, C. Hart. Laws of Temperature Control of Geographical Distribution of Terrestrial Animals and Plants. National Geographic Magazine, vol. 6, 1895, pl. 14.

make a close correlation between a type of vegetation and any single factor of the plant environment if in so doing we neglect other factors.

In most of the investigations that have been made in this field the investigators have not fully considered the effect of variations in factors other than the one with which they sought to establish correlations. If they have failed to make their case it is largely because their generalizations from the data in hand were too broad. The vegetation is undoubtedly of value as an indicator of different soil types in regions where climatic conditions are uniform, but correlations established in one region must not be applied to other regions until they have been thoroughly tested and found to hold true.

CORRELATION WITH SOIL MOISTURE.

One of the most successful correlations yet attempted is that between plant associations and water content of the soil. This correlation, set forth in 1823 by Schouw,[a] has been accepted and modified by leading ecologists[b] and has proved one of the most useful generalizations in the study of vegetation. The great ecological divisions of the earth's surface—ocean, forest, grass land, and desert—are largely expressions of this water relation.

Correlations of vegetation with soil type are, in the great majority of cases, really correlations with soil-water content, soil texture being chiefly important to the plant through its influence upon available moisture. One of the greatest difficulties in the local application of this correlation has been the fact that the water relations of the different types of soils have been defined only in a very general way. Because of this fact very little of the water-content work that has been published is of practical value. Determinations are almost worthless unless checked carefully by some such standard as "non-available moisture" or "moisture equivalent" (p. 18). As has been often pointed out, the moisture relations of different soils are so variable that a mere statement of per cent of water means almost nothing. Clay, for example, is as dry as dust to the plant when it contains 18 per cent of water, while most sands are very nearly saturated with 18 per cent of water.

A slight variation in the quantity of available soil moisture would probably have less effect on the character of the vegetation than would a difference in the season of the year or in the length of time during

[a] See Schouw, J. F., "Grundzüge einer Allgemeinen Pflanzengeographie."

[b] See Warming, Eugenius, "Plantesamfund. Grundträk af den ökologiske Plantegeografi," 1895, and "Ecology of Plants," 1909; Schimper, A. F. W., "Pflanzengeographie auf Physiologischer Grundlage," 1898; and Clements, F. E., "Research Methods in Ecology," 1905.

which available water is present. Determinations of water content should be made throughout the entire growing season in order to be of much value in interpreting plant distribution. Observations should also be made during the periods when vegetation is in a resting condition, to determine whether or not this state of dormancy has been produced by lack of water. On the Plains, for example, the water content of the soil in spring and early summer is often sufficient to support a mesophytic[a] type of vegetation, but the fact that the supply is often entirely inadequate during the late summer, autumn, and winter is enough to exclude plants which require considerable water for a longer period, although it may suffice for a short-season grass, which can lie dormant without injury during the remainder of the year.

Difficult as is the attempt to establish a correlation between vegetation and any one factor of the environment which will hold good throughout an extensive region, it is possible to make such a correlation within a limited area where there is more or less uniformity in regard to factors other than the one with which the correlation is attempted.[b]

CORRELATION OF VEGETATION WITH CROP PRODUCTION.

In considering the correlation of natural vegetation with crop production many of the difficulties experienced in correlating vegetation with the physical environment are eliminated. Broadly speaking, the native plants obey the same physiological rules as do cultivated plants having the same general requirements with respect to moisture, heat, and light. Hence, it should be comparatively easy to infer from the differences in the native vegetation produced by differences in the physical environment what would be the effect of similar differences upon cultivated plants.

It is reasonable to believe that correlations can be established between the native vegetation and the possibilities of crop production on a given type of land,[c] for in the end plant growth is the measure of the effect of all conditions which are favorable or unfavorable for agriculture. Methods of soil management, the application of fertilizers, and all such farm practices are tested by the size of the crop produced. Since plant growth is the ultimate measure, it would seem that the character, growth, and condition of the native vegetation must be the best possible indication of a favorable or unfavorable environment on land where crops have not yet been produced.

[a] Mesophytic plants are those which thrive neither in a very wet nor a very dry soil, but are limited to a moist soil. Practically all cultivated plants are mesophytes.

[b] Warming, Eugenius. Ecology of Plants, 1909, p. 70.

[c] Hilgard, E. W. Soils, 1906, p. 314.

We must also recognize that so far as the conditions of growth are concerned many of our native plants are far more exacting than are the cultivated-crop plants. The distribution of most of the native plants is far more limited than that of cultivated plants, and this is partly due to the fact that native plants are more specialized in their requirements as to habitat. Even though the immediate reason for their limited distribution may be that they are unable to compete successfully in the struggle for existence with other plants with which they come into competition outside of the areas where they find the conditions most favorable for their growth, the fact remains that most of them have a more circumscribed habitat than any of the common cultivated crops. This should make it all the safer to state that a certain cultivated plant will find within the range of a certain native plant association the optimum conditions for growth and crop production.

By studying the vegetation of a region from a physiological point of view the conditions for growth indicated by each association can be brought out with sufficient clearness to enable us to predict with a fair degree of confidence the probable success or failure of a particular agricultural crop on land covered by a particular plant association. The final test must, of course, be the success or failure of the crop when grown on the land in question. Correlations based on the condition of crops during an exceptionally favorable season are of value only as long as such conditions are maintained. In order to be really useful the correlations must be made during seasons when the climatic conditions are normal for the region. As the ultimate criterion the yield should be used rather than the condition of the crop at any time previous to harvest.

ENTIRE PLANT COVER A BETTER INDICATOR THAN ANY SINGLE SPECIES.

The entire vegetation, or plant cover as a whole, is a more reliable indicator of conditions than the presence or the condition of any single species. Vegetation is not only an expression of the present conditions, but is to some extent a record of conditions that have obtained during a period of many years. This record is not likely to be greatly altered by a year or two in which conditions depart from the normal. It is this relative stability which makes the vegetation so reliable an index on the Great Plains. Sometimes the rainfall during a series of years is so much above the normal as to give rise to a popular impression that the region has become as humid as eastern Kansas and Nebraska. The character of the native vegetation, however, stamps this as an area where conditions of excessive moisture are never maintained during long periods, or at least during a sufficiently long period to enable mesophytic plants to establish themselves.

In the plant cover as a whole we have a record which is as stable as the most stable single species and as sensitive as the most exacting plant. Any change in the physical conditions produces an immediate effect on the growth of the year, and, to a less extent, on the perennial growth as well. Notwithstanding this, one can read from the vegetation the record of the average and not of the exceptional years. If rightly interpreted the vegetation offers a record far more valuable and far more complete than any series of meteorological observations now available. In the present work we are concerned with soil and atmospheric studies only in so far as they aid in the determination of a direct correlation between native vegetation and crop production.

The effects of mowing, grazing, fires, etc., must be taken into full account in determining correlations. The vegetation which in one place indicates a heavy soil may in another indicate a lighter soil where fires occur occasionally. Vegetation which in one case indicates a rather heavy type of soil with light rainfall may in another case indicate the same type of soil and a heavier rainfall if the land is exposed to excessive grazing. It is necessary, therefore, to determine very carefully the conditions under which particular types of vegetation have developed before attempting to correlate them with the possibilities of crop production.

METHODS.

In using the native vegetation as an indicator the first step is to make a thorough study of the plant cover in order to become familiar with the more important species and the plant associations which they form. The dominant associations as well as the less important ones should be clearly recognized and defined. The definition of the various associations is best accomplished by the use of modern ecological methods. The method found most valuable in the present work was that known as the quadrat method.[a]

Where exact records of the structure of the plant cover were desired, a quadrat of 1 yard (or 1 meter) was mapped in detail on cross-section paper (fig. 1). These maps were most useful as records of typical portions of plant associations. The areas occupied by the different plant associations were mapped by means of colored pencils on blank township maps on a scale of 1 inch to the mile. When once the plant associations were clearly distinguished, the geographical distribution of each association could be readily recorded by this method.

In addition to the work mentioned above there is the much more difficult task of determining what factors have brought about the

[a] See Clements, F. E., "Research Methods in Ecology," 1905, p. 161.

groupings of plants into these definite associations. Important as are the factors of reproduction, dissemination, and establishment, or of invasion and succession in the early stages of the associations, it is largely in the physical inequality of the plant habitat that we find the reason for the present distribution of vegetation in the region under consideration.

In studying the factors which have contributed to the origin of a particular association we have then to take into account, first of all, the physical conditions under which the association thrives. In doing this for the region here discussed all available data have been used. Air-temperature and rainfall records were easily obtained; an accurate record of evaporation, saturation deficit, soil moisture, and soil temperature is taken[a] at 11 different stations on the Great Plains. These more general records have been supplemented by many simultaneous comparative observations made by the writer in the different plant associations.

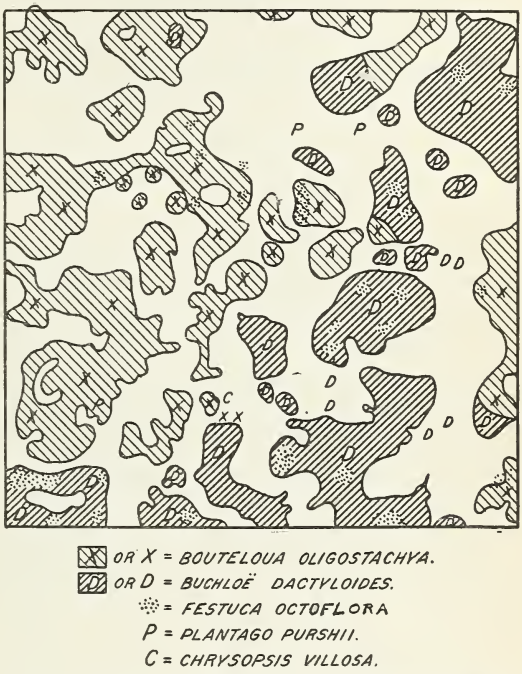

FIG. 1.—A one-meter quadrat, from the grama-buffalo-grass association (short-grass formation) at the Dry-Land Agriculture Experiment Farm, Akron, Colo.

Water is the chief "limiting factor" for plant growth in the Great Plains area. It was therefore necessary to know the amount present in the soil during the period covered by these investigations. A series of determinations made at a carefully chosen base station twice a day throughout the season gave the most valuable data that were obtained, but it was also found desirable to make occasional determinations of soil moisture at other points. These occasional determinations were made both at the same time in different plant associations and at different times in the

[a] Under the direction of Dr. L. J. Briggs, of the Physical Laboratory of the Bureau of Plant Industry.

same association, the choice of the location and time depending upon the weather and the condition of the vegetation.

The soil moisture was actually determined in percentages of water to dry weight of the soil, but in this shape the data are of little value for comparing the behavior of plants growing on soils of different texture. It was found necessary, in order to make such comparison, to reduce the data to some definite standard. The best standards for a comparison of moisture conditions in different types of soil in relation to plant growth and behavior were found to be the moisture equivalent and the nonavailable moisture.[a]

The rate of penetration is of such importance in influencing the amount of water in the soil that it was considered essential to make careful measurements of the time required for a given amount of water to enter the soil, and also of the quantity of water taken up by the soil during a rainfall of known amount.

Chemical and mechanical analyses of soils were necessary as a check upon the correlations between soil moisture and plant distribution. The analyses required were obligingly furnished by the Bureau of Soils.

Plant migrations, invasions, and successions are of great importance in considering the origin and present structure of plant associations. In order fully to understand each particular association, how it has originated and what conditions it indicates, it was necessary to go somewhat in detail into the subject of competition between different species. In this connection a study of the root systems of the different species, as well as of the effects produced on the vegetation by fires, and by mowing, grazing, and other human and animal agencies, was found to be indispensable.

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[a] The moisture equivalent is the amount of water left in the soil when saturated soil has been subjected to a force of 1,000 times gravity. (See Briggs, L. J., and McLane, J. W., "The Moisture Equivalents of Soils," Bulletin 45, Bureau of Soils, U. S. Dept. of Agriculture, 1907.)

The nonavailable moisture is the amount of water which remains in the soil after the plant has wilted as a result of insufficient moisture. (See Sachs, Julius, "Bericht über die physiologische Thätigkeit an der Versuchstation in Tharandt," Landw. Versuchs-Stationen, 1859, vol. 1, p. 235.) The nonavailable moisture, expressed in percentages, is here used to signify the maximum percentage of water in the soil which can not be utilized by the plant, or what might be called the point of nonavailable maximum. When the amount recorded is less than this maximum nonavailable it is referred to as below the nonavailable. In figures 5 to 10, inclusive, the nonavailable maximum is represented by the zero line. (For a statement of the relation of moisture equivalent to nonavailable moisture see Table XII, p. 78.)

Hygroscopic coefficient (Hilgard, E. W., Soils, 1906, p. 196) is more difficult to determine and more easily affected by fluctuations in temperature or humidity, and on this account is not as useful as the other determinations here mentioned.

In studying a succession [a] it is necessary, first of all, to have a comprehensive knowledge of the established vegetation and to supplement this by a careful study of associations occupying adjacent areas which might influence its structure. One should clearly recognize the great primary successions which have led to the establishment of the existing vegetation, since these must be taken into account in considering the indicator value of any particular association. On the Great Plains it was necessary to extend observations over a wide area, for no correct idea of succession can be obtained unless this study has been sufficiently extended to enable one to secure a view of practically the whole field of plant migration which is directly concerned in shaping the particular association under observation.

PLANT FORMATIONS AND ASSOCIATIONS IN EASTERN COLORADO.

SCOPE OF THE INVESTIGATIONS.

While this work has been carried on to some extent in all the States in the Great Plains region, the more detailed investigations have been confined to Washington and Yuma counties, in eastern Colorado. The results are not expected to apply in their smaller details except in the region lying north of the Arkansas River and south of the South Platte, in eastern Colorado. Correlations must be somewhat modified in passing beyond the limits of this area, but with slight modifications they will probably hold good in a general way for most of the Great Plains region.

The survey of the vegetation of this region was undertaken by the use of methods outlined by Clements ("Research Methods in Ecology," 1905), somewhat modified and extended to suit the special conditions under which the work was carried on.

CLASSIFICATION OF VEGETATION TYPES.

In the classification of the plant associations no attention is paid to those associations found along the creek banks or in marsh and alkali flats, for the reason that the work is intended primarily to deal only with the vegetation of that portion of the area which receives its water supply directly from precipitation.

[a] Succession is the phenomenon of replacement of one type of plant cover by another. This change in vegetation is brought about in many ways. The plants themselves, by gradually changing the conditions, are often the most important factor in bringing about the change. Successions have been classified as to their initial cause as primary (those dealing with the revegetation of newly formed land) and secondary (those brought about by the destruction or removal of the original vegetation). Secondary successions occur most commonly as the result of human agency. (See Clements, F. E., "Research Methods in Ecology," 1905, p. 239.)

The more important plant groups which constitute the vegetation of eastern Colorado and the more important species of each group are here listed in such a way as to indicate the structural and historical relationships of the groups.

Classification of vegetation types.

Formation.[a]	Association.[b]	Society.[c]	Dominant species.
Lichen			Rinodina oreina. Lecanora calcarea. Parmelia conspersa.
Short-grass			Bouteloua oligostachya. Buchloë dactyloides.
	Gutierrezia-Artemisia		Gutierrezia sarothrae. Artemisia frigida. Bouteloua oligostachya.
	Grama-buffalo grass		Bouteloua oligostachya. Buchloë dactyloides.
		Psoralea tenuiflora	Bouteloua oligostachya. Buchloë dactyloides. Psoralea tenuiflora.
		Aristida longiseta	Bouteloua oligostachya. Buchloë dactyloides. Aristida longiseta.
	Wire-grass		Bouteloua oligostachya. Aristida longiseta. Psoralea tenuiflora.
Prairie-grass			(*d*)
	Bunch-grass		Andropogon scoparius.
	Sand-hills mixed		Bouteloua hirsuta. Andropogon hallii. Calamovilfa longifolia. Artemisia filifolia.
	Blow-out		Redfieldia flexuosa. Muhlenbergia pungens. Psoralea lanceolata.

[a] The plant formation is the most important vegetation type, and signifies a group of plants which have the same general growth form, or appearance. While different portions may differ widely as to the species which form the plant cover, they are similar in general outward appearance and indicate more or less uniform environmental conditions. (See Warming, E., Ecology of Plants, 1909, p. 139; and Clements, F. E., Research Methods in Ecology, 1905, p. 292.)

[b] The term "plant association" is used here in place of the technical term "consocies" (Clements, Research Methods in Ecology, 1905, p. 295). The association is usually more uniform as to species than the formation and occurs only as a major division within the formation (Warming, Ecology of Plants, 1909, p. 144).

[c] A plant society is a phase or aspect of an association characterized by some one or a few predominant species.

[d] Since only the western portion of this formation is considered, the dominant species for the entire formation can not be given.

In addition to the associations listed under the short-grass formation there are two other associations which are of great importance when considering the vegetation of the Great Plains area as a whole but which occupy a very small area in eastern Colorado. They are omitted from the above classification because it is difficult to show the relationship of the important associations when these are also listed. These associations, relatively of small importance in eastern Colorado, are as follows:

Supplementary classification of vegetation types.

Formation.	Association.	Dominant species.
Short-grass		Bouteloua oligostachya. Buchloë dactyloides.
	Grama grass	Bouteloua oligostachya.
	Wheat-grass	Bouteloua oligostachya. Buchloë dactyloides. Agropyron smithii.

A detailed botanical description of the formations and associations would be out of place in the present publication, but it seems desirable to connect these associations with those described by Pound (Roscoe) and Clements (F. E.) in the "Phytogeography of Nebraska," 1900. It must be remembered that the Nebraska work was pioneer work, and that while it was most carefully and thoroughly done, a fuller knowledge of the development of the vegetation of the plains has made it undesirable to follow closely the grouping therein set forth. The present classification corresponds only in a general way with that adopted by Pound and Clements.

As understood by the writer, the short-grass and prairie-grass formations cover practically all of the area east of the mountains and west of the Mississippi Valley forest area.

The short-grass formation in the writer's conception includes the following formations recognized by Pound and Clements, which are discussed in the "Phytogeography of Nebraska," on the pages indicated: Buffalo-grass formation, 350; Stipa formation, 381; Agropyron formation, 383; peppergrass-cactus formation, 386; beard-grass formation, 361. The Agropyron formation of Pound and Clements corresponds to the writer's wheat-grass association, and their buffalo-grass and peppergrass-cactus formation corresponds to the writer's grama–buffalo-grass association. The beard-grass formation of the "Phytogeography of Nebraska" corresponds to the wire-grass association of the present publication, and is placed by the writer in the short-grass formation because of the preponderance of grasses of the short-grass type, although it is clearly an intermediate association between the two great formations.

The prairie-grass formation, as described by the writer, is also much more comprehensive than the formation of the same name as understood by Pound and Clements (p. 348). It includes the writer's bunch-grass association, which corresponds to a part of the bluestem type of the bunch-grass formation (Pound and Clements, p. 355), and the writer's sand-hills mixed association, which also corresponds to a part of the bluestem type of the bunch-grass formation (Pound and Clements, p. 355), and to the *Artemisia filifolia* formation (Pound

and Clements, p. 372). The blow-out association of the writer corresponds to the blow-out formation of Pound and Clements (p. 365), and in the present publication is included in the prairie-grass formation, because it invariably passes directly into one of the associations of that formation. The *Artemisia filifolia* formation of Pound and Clements (p. 372) is included in the sand-hills mixed association of the writer because of the fact that this species of Artemisia so generally occurs in this association. The bunch-grass association, as it occurs in eastern Colorado, is a much more nearly closed[a] association than in portions of Nebraska, and what is said in this paper relative to the conditions indicated by this type of vegetation applies only when the ground is well covered and the vegetation is of the closed type rather than of the open type so often met with on the more unstable sand hills of Nebraska.

The great prairie-grass formation includes many associations which flourish east of the Great Plains area and are not here considered. The *Artemisia tridentata* formation, one of the principal formations occurring in the mountain region west of the Great Plains area, is found in places within the latter area, but does not belong to either the prairie-grass or the short-grass formations.

GEOGRAPHICAL DISTRIBUTION OF THE FORMATIONS.

THE LICHEN FORMATION.

Plants of the lichen formation occur wherever there are rock outcrops or where the soil is covered or partially covered with rock fragments. Naturally they are most important near the mountains.

THE SHORT-GRASS FORMATION.

Occupying the greater part of the Great Plains area, the short-grass formation in the United States extends from southern Texas to northern Montana and Dakota, and from the Rocky Mountains eastward to where it meets the prairie-grass formation in central Texas, Nebraska, and the Dakotas. It is limited on the east by the increasing moisture, which enables the deeper rooted, taller, and more mesophytic prairie-grass species to kill out the short grasses by competition. On the west it is limited by the mountain ranges with their woody vegetation, and in the intermountain areas by the xerophytic conditions which are the direct result of winter rains and dry summers. This condition of almost exclusively winter rainfall is entirely unfavorable for the shallow-

[a] Reference is here made to an association or formation in which the ground is closely covered with plants. Technically a closed formation is one into which other plants can not migrate without displacing some of those already established.

rooted short grasses, but is congenial to a scattered growth of deep-rooted plants, such as makes up the great *Artemisia tridentata* formation of the intermountain areas. Within the short-grass formation there are several well-marked associations.

The Gutierrezia-Artemisia association must be regarded as an early stage in the short-grass formation and often represents a transition from the lichen formation. It is an important association near the mountains, notably in northeastern New Mexico and southeastern Colorado, but it also occupies extensive areas in other portions of the Great Plains, especially in places where there are outcrops of only partly disintegrated rock.

The grama-grass association is best developed in the northern Great Plains, especially in Montana and extending south along the mountain front to central Colorado.[a] It is not an important association in eastern Colorado.

The grama–buffalo-grass association is the most extensive subdivision of the short-grass formation. It predominates over the whole central portion of the Great Plains area and extends far south into Texas. In the southwestern portion it is somewhat modified by the occurrence of *Muhlenbergia gracillima* Torr., and upon further investigation this portion may prove to belong to another association.

The wheat-grass association is best developed in South Dakota, west of the Missouri River, on the adobe soil derived from the Fort Pierre shale, but it also occurs in detached areas both north and south of this region.

The wire-grass association is found chiefly in that portion of the short-grass formation which is adjacent to the prairie-grass formation. In eastern Colorado, where it covers a considerable area, it usually borders the sand hills.

THE PRAIRIE–GRASS FORMATION.

Most extensively developed in the eastern part of the Great Plains, the prairie-grass formation is limited on the east by the conditions favorable to the growth of trees with which the plants of this formation can not directly compete. The burning of the prairie grasses when they are dry is very detrimental to tree growth, and since these fires are often started by lightning the migration of trees into grassland areas, even before the advent of man, must have been accomplished with great difficulty. On this account the prairie grasses were able to occupy a great deal of land in regions where the moisture

[a] Shantz, H. L. A Study of the Vegetation of the Mesa Region East of Pikes Peak: The Bouteloua Formation. Botanical Gazette, 1906, vol. 42, pp. 16–47 and 179–207.

conditions were favorable to tree growth. While limited on the east by plant competition, this formation is limited on the west by the low water content of the soil. Although the physical environment in the prairie-grass formation is favorable to the short grasses, they are shut out by direct competition with the taller and deeper rooted species. On the other hand, as we pass westward the prairie grasses are gradually shut out by insufficient water supply and the short grasses are left in possession. Within the area of the present investigations the prairie-grass formation is represented only by the bunch-grass association, the sand-hills mixed association, and the blow-out association.

The bunch-grass association embraces the type of native vegetation that, according to early reports, originally occupied eastern Kansas.[a] It extends northward in a somewhat modified form into the Dakotas and southward in a typical form far into Texas. It pushes westward on sandy land into the midst of the short-grass formation, occupying large areas in western Nebraska and Kansas, eastern Colorado, and northern Texas.

The sand-hills mixed association occupies extensive areas in sand-hill regions, and has practically the same distribution as the bunch-grass on the sandy lands of western Kansas and Nebraska, eastern Colorado, and northern Texas.

The blow-out association represents the earliest stages of the sand-hills mixed association and is highly developed only in the regions of moving sand.

ASSOCIATIONS IN EASTERN COLORADO WHICH INDICATE LAND OF AGRICULTURAL IMPORTANCE.

THE GRAMA–BUFFALO-GRASS ASSOCIATION.

General Appearance.

Representing the most typical form of the short-grass formation, the grama–buffalo-grass association presents an appearance of extreme monotony. The plant cover is uniform and velvet-like; in some places it covers practically the whole surface of the ground; but in other places it is broken up into alternating spaces of open ground and dense, mat-like cover (fig. 1). The amount of soil surface covered varies from as low as 10 per cent to as high as 90 per cent. The plant growth is usually closest where there is a mixture of buffalo grass and grama grass. Where grama grass largely predominates the vegetation is often of the open-mat type. (See p. 44.) In the pure form of this association there are practically

[a] Hall, Elihu. Notes on Some Features of the Flora of Eastern Kansas. American Journal of Science and Arts, vol. 50, 1870, pp. 34, 35.

no plants which rise above the short-grass layer. Reference to Plate I, figure 1, will give the best idea of the general appearance of this type of vegetation.

Botanical Composition.[a]

In eastern Colorado the short-grass vegetation is composed almost entirely of two species, grama grass (*Bouteloua oligostachya* (Nutt.) Torr., fig. 2) and buffalo grass (*Buchloëdactyloides* (Nutt.) Engelm., fig. 3). It is not an uncommon thing to find areas (Pl. I, fig. 1) in which no other plants are apparent. Close examination, however, will show that there are other plants associated with these grasses (fig. 1).

No attempt is here made to give a complete list of the plants which may occur in this association in addition to grama grass and buffalo grass, but a few of the more important species are given in the order of their importance in the lists below.

Fig. 2.—Grama grass (*Bouteloua oligostachya*). Typical plant, *a*; empty glumes, *b*; perfect and imperfect flowers, *c*.

[a] Under this heading it seems best to give botanical names with citations of the author for convenience in referring to any standard manual for a botanical description of the plants. Author citations are thus avoided in other portions of the text except in connection with names which do not occur in the lists under this and similar headings. The following works will be found to be most useful in identifying the plants of this region: Britton, Manual of the Flora of the Northern States and Canada, 1901; Rydberg, Flora of Colorado, 1906; Robinson and Fernald, Gray's New Manual of Botany, 1908; Coulter and Nelson, New Manual of Botany of the Central Rocky Mountains, 1909.

Specimens of the species mentioned in this paper will be found on deposit in the National Herbarium, with the writer's identifications and reference to this bulletin.

The annual growth which occasionally becomes quite noticeable during June is composed largely of:

Festuca octoflora Walt.
Plantago purshii R. & S.
Draba micrantha Nutt.
Dysodia papposa (Vent.) Hitchc.
Salsola pestifer A. Nels.
Munroa squarrosa (Nutt.) Torr.
Leptilon canadense (L.) Brit.
Chenopodium leptophyllum (Moq.) Nutt.

FIG. 3.—Buffalo grass (*Buchloë dactyloides*). Pistillate plant, *a;* staminate plant, *b;* pistillate spike, *c;* staminate spikelets, *d*.

The Festuca is the most important of these annuals. It is one of the most noticeable plants during wet periods in early spring. Often the landscape appears bright green largely because of the luxuriant growth of this small annual grass. It requires a very short season and will ripen in about thirty days. At its ripening period the appearance of the landscape is brown and dead. *Plantago purshii* is probably as uniformly distributed but not usually so abundant as the Festuca.

There is great variation from year to year in the amount of growth of these native annuals. They are especially abundant and noticeable during wet years. All are diminutive, the smaller plants of each species being hardly more than an inch in height, while the larger plants seldom reach a height of more than 6 inches. They are all short-season plants and are able to ripen a few seeds even under most unfavorable conditions.

The following longer lived plants are commonly found in this short-grass cover:

Schedonnardus paniculatus (Nutt.) Trelease.
Opuntia polyacantha Haw.
Opuntia fragilis Haw.
Echinocereus viridiflorus Engelm.
Mamillaria vivipara (Nutt.) Haw.
Malvastrum coccineum (Pursh) Gray.
Grindelia squarrosa (Pursh) Dunal.
Astragalus crassicarpus Nutt.
Sitanion hystrix (Nutt.) Smith.
Ptiloria pauciflora Raf.
Gaura coccinea Pursh.
Erigeron canus Gray.
Aragallus lambertii (Pursh) Greene.
Astragalus mollissimus Torr.
Erysimum asperum DC.

Of the longer lived plants which commonly occur in this short-grass cover one of the most noticeable is the cactus (*Opuntia polyacantha*), which forms extensive societies [a] at many places in the Great Plains. In eastern Colorado cactus occurs commonly, but is seldom of importance. Evidence shows that it was once far more abundant than at present, and many of the plants now found are dying as a result of fire and the attacks of parasites.

Schedonnardus and Malvastrum are found almost everywhere, but they never become dominant on the native sod. Grindelia in some places develops so abundantly that it becomes the most noticeable feature, dominating an extensive plant society.

Most of the plants listed have a root distribution approximately the same as that of the short grasses themselves. An exception is noted in the case of the species of Astragalus, which are deeper rooted, but, on the other hand, require only a very brief growing season.

Plants which often occur here but which are more characteristic of other associations within this formation are as follows:

Artemisia frigida Willd.
Gutierrezia sarothrae (Pursh) B. & R.
Aristida longiseta Steud.
Psoralea tenuiflora Pursh.
Agropyron smithii Rydb. (A. occidentale Scribn.).
Sideranthus spinulosus (Pursh) Sweet.
Chrysopsis villosa Nutt.
Eriogonum effusum Nutt.
Liatris punctata Hook.

All, or nearly all, of the species in the above list are better developed in the wire-grass association (p. 48), and their occurrence amid short grass, especially if they are abundant, indicates conditions approaching those found where the wire-grass association occurs. Several of these species reach their highest development in the Gutierrezia-Artemisia association (p. 60). The significance of the presence of these species is discussed in connection with these other two associations.

Physical Conditions Indicated.[b]

SOURCE OF DATA.

In order to give a clear account of the conditions under which the short grasses succeed, it is necessary to present some of the physical

[a] See footnote *c*, p. 20.

[b] The physical conditions of land originally occupied by vegetation of this type when under cultivation are discussed on p. 70.

data obtained at Akron, Colo.,[a] during the growing season, from June 2 to September 27, 1909.

In presenting these data only such records as are indispensable to the explanation of the conditions indicated by the different associations are included. Temperature, light, evaporation, etc., are practically uniform throughout eastern Colorado. The seasonal distribution of rainfall or the monthly rainfall is of far greater importance than annual rainfall, and is given here in order to help explain the conditions found in the different associations. Rainfall is the same for the different plant associations, and although this factor is discussed under only this one association the discussion applies equally to the others.

RAINFALL.

The following is the daily rainfall record in inches for the entire growing season of 1909 as recorded by the Physical Laboratory of the Bureau of Plant Industry at the Akron Experiment Farm.[b] This record gives a very good idea of the daily distribution of rainfall and is indispensable in interpreting the soil-moisture curves (figs. 5, 6, 7, 8, 9, and 10). A comparison of the diagrams in figure 4, as well as a comparison of the actual data on which these are based as given in Tables I and II, show very clearly that the season during which the soil-moisture determinations were made was unusually wet.

TABLE I.—*Days of rainfall and the amount of daily rain at Akron, Colo., April 1 to September 30, 1909.*

Day of the month.	Rainfall in inches.						Day of the month.	Rainfall in inches.					
	Apr.	May.	June.	July.	Aug.	Sept.		Apr.	May.	June.	July.	Aug.	Sept.
1	.....	.....	0.06	.....	.....	0.13	19	.....	0.42	0.02	.....	.....	.....
2	.....	.....	.01	.....	.....	1.12	20	0.14	.31	.08	.....	.....	.....
4	0.14	.....	.....	0.02	.....	.23	21	.....	.....	.....	0.01	.....	.....
5	.06	.....	.01	.....	.....	.04	22	.....	.06	.....	.....	.....	.....
6	.....	.....	1.02	.01	.....	.....	23	.....	.08	.....	.....	.....	.....
7	.02	Tr.	.07	2.39	0.48	Tr.	24	.....	.17	.07	.08	0.06	.....
8	.....	.....	.04	.32	.96	.....	25	.....	.08	.....	.....	.....	.....
9	.....	.....	1.06	.09	.....	.....	27	.....	.....	.....	.80	.....	.....
10	.....	.....	.30	.....	.....	.....	28	.....	.12	.....	.....	.....	.....
11	.04	.....	.26	.....	.....	.....	29	.....	.....	.....	.89	.....	.....
12	.....	0.04	.....	.....	.....	.36	30	.....	.34	.....	.....	.....	.....
13	.....	.....	.32	.....	.....	.28	31	.....	.19	.....	.....	.89	.....
14	.....	.....	.....	.....	.74	.....							
17	.....	.06	.....	.....	.....	.....	Total.	.40	1.87	3.32	4.61	3.77	2.16
18	.....	.....	.....	.....	.64	.....							

[a] The writer's headquarters during the season of 1909, when the data here presented were largely obtained, were at the experiment farm of the Office of Dry-Land Agriculture, 5 miles east of Akron, Colo. The farm is located in an area covered by short-grass vegetation.

[b] Free access to the records in the office of the physicist of the Bureau of Plant Industry was accorded the writer. To Dr. L. J. Briggs the writer is indebted for the records of rainfall and evaporation at the Akron Experiment Farm, for moisture equivalent and hygroscopic moisture determinations of many soil samples, and for many determinations of moisture content on the cultivated plats. Although not here included, these records greatly aided in the general discussion of the conditions favorable or unfavorable for crop production on the short-grass land.

TABLE II.—*Average, maximum, and minimum monthly rainfall recorded at twelve stations in eastern Colorado previous to the year 1909.*

Month.	Average.	Maximum.	Minimum.	Month.	Average.	Maximum.	Minimum.
January	0.32	2.35	0	July	2.77	6.72	Trace.
February	.52	1.98	0	August	2.23	6.64	Trace.
March	1.08	4.47	Trace.	September	1.05	3.73	0
April	2.48	11.11	Trace.	October	1.00	3.20	0
May	2.46	9.77	Trace.	November	.46	4.40	0
June	2.61	6.30	.72	December	.42	2.00	0

The average monthly rainfall, as shown in Table II, is based on all of the monthly records up to and including 1908 for the following stations in eastern Colorado: Akron, Fox, Wallet, Burlington, Holyoke, Wray, Cheyenne Wells, Julesburg, Yuma, Cope, Siebert, and Leroy. The average length of record for the twelve stations is 13.4 years, and these data should give a very good general idea of the distribution and amount of monthly rainfall for this portion of the Great Plains. The least and the greatest monthly rainfall are also of interest to show the extremes.

The annual rainfall alone gives almost no idea of the conditions favorable or unfavorable for crop production, for crop failures often occur during the years with the greatest annual rainfall. The average annual rainfall for the twelve stations is 17.40 inches. The greatest annual rainfall for this region was recorded at Cope in 1898 and was 28.48 inches, while the lowest annual rainfall, 5.70 inches, was in 1893, at Fox, a few miles distant from Cope. There is no evidence, either from the vegetation or from the oldest of the Weather Bureau records, that the rainfall is permanently increasing or decreasing in amount.[a]

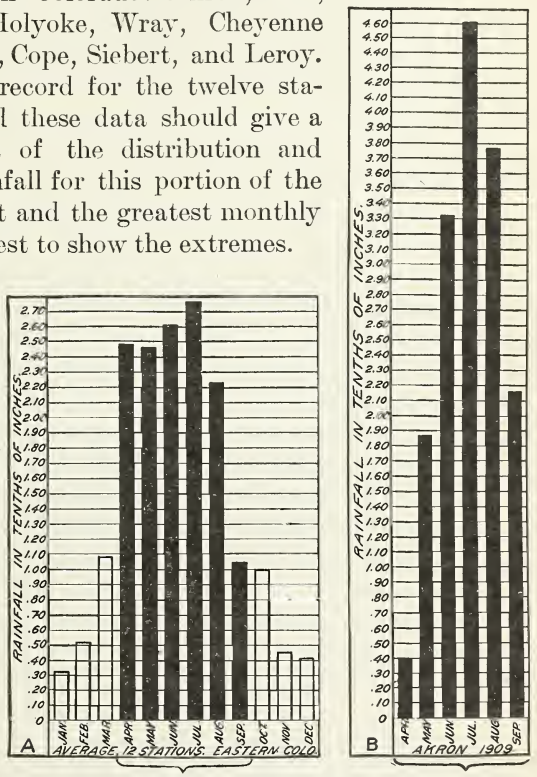

FIG. 4.—Diagrams showing: *A*, The average monthly precipitation based upon all records from twelve stations in eastern Colorado; *B*, the rainfall at Akron, Colo., season of 1909, for the months April to September, inclusive.

[a] U. S. Weather Bureau, Precipitation in Western Kansas, Abstract of Data No. 2, 1907.

SOIL-MOISTURE CONTENT.

Soil-moisture determinations were taken on the Akron Experiment Farm twice a day from June 10 to September 10, 1909.[a] This sampling was done with a soil tube. In the morning samples were taken to a depth of 6 feet, the first 3 feet being in 6-inch samples while the second 3 feet were taken in samples of 1 foot each. In the evening samples were taken for each 6 inches to a depth of 3 feet only. Each sample for a given depth consisted of three cores. Several series of samples were taken before June 10 and one series of samples on September 27, thus extending the records from June 2 to September 27. In collecting this series of samples care was taken to select spots where comparatively pure short-grass cover occurred. Samples were taken as near together as possible, but with precautions to insure against the effect of water penetration from the holes where previous borings were made. The samples were thoroughly dried in an oven at 100° C. and the moisture content expressed in percentages of the dry weight of the soil.

The seasonal variations in available soil moisture, as calculated from the results of the daily sampling just described, are shown in the curves in figures 5, 6, 7, 8, 9, and 10. Each curve is made up of 184 points, except that curves for the soil below 36 inches contain only 95 points. The fluctuations observed in these curves are due largely to variations in the texture of the soil. These variations occur even at the short distances apart at which the corresponding samples were taken on successive dates. This is especially true with respect to the curves representing the water content in the deeper layers of the soil. In many places where the determination showed a low moisture content the soil sample was sandy; where high the soil contained more clay. If it had been possible to check each individual determination by a moisture equivalent or nonavailable moisture determination[b] the curves would show much less variation. However, the general trend of the curve is not vitiated by these fluctuations, since it is clear that they do not represent actual gain and loss in water but are the result of extremely local variations in soil texture.

The curves are based upon determinations of actual water content corrected to represent the amount of water available to the roots of

[a] Prof. L. F. Childers, now of the Idaho Experiment Station, assisted the writer in this work as special agent of the Bureau of Plant Industry at Akron during the summer of 1909.

[b] See footnote, p. 18.

Kubanka wheat, as estimated from the moisture equivalent of soil from each depth.[a] In order to read them in terms of the actually observed water content it is necessary to add to the percentage represented at each point on the curves for the respective depths the percentages recorded in Table III.

TABLE III.—*Water nonavailable for Kubanka wheat in percentages of dry weight of soil, estimated from the moisture equivalent of a composite sample of all soil taken at each depth.*[a]

Depth in inches.	Per cent.	Depth in inches.	Per cent.	Depth in inches.	Per cent.
0- 6	9.6	18–24	10.5	36–48	7.1
6–12	14.5	24–30	9.2	48–60	7.0
12–18	12.8	30–36	7.9	60–72	6.3

The most interesting thing brought out by these curves is the fact that during the period of observation the rainfall did not at any time alter the water content of the soil below the first 18 inches. In fact, the curve representing the depth 12 to 18 inches was not influenced by a rainfall of as much as 2.40 inches on July 7 (fig. 5), nor by any of the rains which occurred later in the season (figs. 5 and 6).

A rainy period during the last of May and early June, before regular soil sampling was begun, influenced considerably the soil below 18 inches, as is shown by the subsequent general decline of the curves for 18 to 24 and 24 to 30 inches (fig. 7, *A;* fig. 8, *A*), from June 10 to about July 22, after which they remain approximately constant. The curves (fig. 7, *B;* fig. 8, *B*) show that the moisture content of this soil below 3 feet was not increased at any time during the season as a result of precipitation occurring after the sampling was begun and that on this hard land, even during the period when there was much more than the normal rainfall, the soil moisture available for Kubanka wheat was limited to the surface 3 feet of the soil.

Table IV summarizes the average available and nonavailable water between certain dates for each depth of the soil, and shows clearly the periods when water was available or not available. The average for each depth for the whole period is also given.

[a] See Table XII, p. 78, and footnote. The particular lot of seed used in the pot-culture experiments by which the nonavailable moisture was determined for Kubanka wheat was that distributed by the Department of Agriculture, under Seed and Plant Introduction No. 5639.

TABLE IV.—*Periods when water was available and amount at each depth, in percentage of dry weight of soil, also general average at each depth for the whole season, June 7 to September 10, 1909.*

Depth of soil sampled (inches).	Period.	Average percentage of available water.	
		For period.	For whole season.
0–6	June 7 to June 24 a. m.	9.8	4.81
	June 24 p. m. to July 6	− 1.56	
	July 7 to July 19 a. m.	7.82	
	July 19 p. m. to July 26	− 1.71	
	July 27 to August 4 a. m.	4.67	
	August 4 p. m. to August 7	− 2.51	
	August 8 to August 27 a. m.	4.23	
	August 27 p. m. to August 31	− 2.32	
	September 1 to September 10	12.81	
	September 27	1.0	
6–12	June 7 to July 22 a. m.	5.67	2.72
	July 22 p. m. to September 3	− .40	
	September 4 to September 10	4.08	
	September 27	2.8	
12–18	June 7 to July 18 a. m.	4.84	1.25
	July 18 p. m. to September 10	− 1.54	
	September 27	− 1.7	
18–24	June 7 to July 19	3.23	.56
	July 20 to September 10	− 1.43	
	September 27	− 2.0	
24–30	June 7 to July 19	1.72	.23
	July 20 to September 10	− .81	
	September 27	− 2.1	
30–36	September 27	− 1.2	.04
36–48	do	− 1.2	− .61
48–60	do	− .3	− .09
60–72	do	.3	.02

As previously shown (fig. 4, p. 29), the season of 1909 was abnormally wet. Notwithstanding this fact, there were three periods when practically no water was available in any depth of the soil reached by the borings. These periods were from the evening of July 23 to the evening of July 26, inclusive; from the evening of August 4 to the evening of August 7, inclusive; and from the morning of August 28 to the evening of August 31, inclusive.

Below 6 inches there was no available water from July 22 to September 3, and below 12 inches there was none available later than July 19. Water was available in the soil at the depth of 30 to 36 inches during only a few days in June, and there is no evidence to show that water was again available in this layer after June 11. The soil below a depth of 36 inches was not influenced by the rainfall and its water content was practically constant through the season.

It is evident that except as an immediate result of the rainfall of a single day no water was available at any depth after July 22, and that even at such times the water available was found only in the

surface foot of soil. For the period July 22 to September 1 the only available water at any time was in the surface 6 inches. The second 6-inch layer was only slightly affected by several rather heavy rains, and was brought above the nonavailable point by only two heavy rains, August 31 and September 1. It is also interesting to see that more than three days passed before the water added by these rains occasioned an increase in the water content of the second 6 inches.

The water content of the first 6 inches varied more than that of any other depth. During the season the water content of this first 6-inch layer fell below the available for several days at four different periods.

The water content of the soil from 6 to 12 inches remained below the available for a long period, July 22 to September 3, and also for the three days July 5 to 7. The water content of the soil from 12 to 18 inches did not fall below the point of availability until July 18, but after that date did not again rise to this point although many heavy rains were recorded. The same is true of the soil at depths of 18 to 24 inches and 24 to 30 inches.

A comparison of the rainfall at Akron during the season when these soil-moisture records were made with that of the average season for twelve stations in eastern Colorado (fig. 4) shows clearly that the seasonal rainfall was not only greater than the normal, but also that the period of greatest monthly rainfall began one month later and continued one month later than the normal. This being true it is probable that in a normal year the period of drought would occur much earlier in the season and that conditions would be much less favorable for the growth of plants.[a]

The point at which the water content of the soil becomes nonavailable for Kubanka wheat is comparatively low. From many observations in the field during several seasons and from experiments in the laboratory it is believed to be almost as low as that representing the nonavailable for many of the native plants of the grama–buffalograss association. This probability is supported by a consideration of the moisture content of the soil below 6 inches (fig. 6), which is protected from direct evaporation by the soil above. Nothing in the curves indicates that the native plants still extracted water from the deeper layers of the soil when their water content was below the available minimum for Kubanka wheat.

[a] Daily soil-moisture determinations on this type of land to a depth of 10 inches, at Yuma, Colo., during July, 1907, showed available water in the soil during only seven days in the month, and occasional determinations during August, 1907, showed the soil to be much drier even than during July.

RUN-OFF.[a]

A great quantity of rainfall runs off directly and never enters the soil. The extent of the run-off, indicated by the many large, dry, gravelly stream beds which are found in short-grass regions, has been demonstrated by actual observation during heavy rains and by the measurements here recorded. From the results of the moisture determinations—the weight of the soil, the percentage of water it contains, and the amount of precipitation being known in each case—the quantity of water which entered the soil and the quantity of run-off was easily computed. At the place where the soil samples were taken and the run-off measured the land was comparatively level. It was possible, however, for water to drain over this area from the land adjacent on the north, and consequently the run-off recorded from this particular area was lower than the average for the region.

The results of all records of run-off at the base station at Akron, Colo., from June 11 to September 10 are given in summary form in Table V.

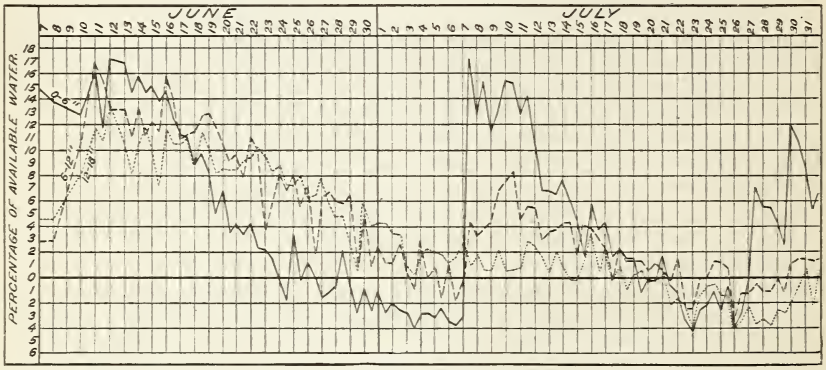

FIG. 5.—Diagram showing the daily available soil moisture, from morning and evening determinations for each 6-inch layer, 0–18 inches, in pure short-grass land, at Akron, Colo., Dry-Land Agriculture Experiment Farm, June and July, 1909.

The figures represent the average of the total quantity of water which entered the soil and which ran off, expressed in percentages of the total rainfall; they are not the results of averaging the percentages of run-off and penetration for each individual rain.

[a] Variation in the water content of the surface soil, in the rate and amount of precipitation, in the physical condition of the soil surface, and in the slope all affect the amount of run-off. The run-off from the same area will therefore vary greatly at different times. The data given in Tables VI to XI, inclusive, were obtained at points where the slope of the land and the rate and amount of precipitation were the same, the chief factors which produced the variation having been differences in the water content of the soil and the physical condition of its surface. Comparisons of the data given in any one of these tables with those in any other must be checked by reference to the continuous record made at the base station. Direct comparisons of one table with another will lead to entirely erroneous conclusions.

TABLE V.—*Percentages of the total amount of run-off and of penetration on short-grass land at the base station, Akron, Colo., June 11 to September 10, 1909.*

Rainfall.	Number of rains.	Penetration.	Run-off.
		Per cent.	*Per cent.*
Rains of 0.10 inch or more	12	85	15
Rains of 1 inch or more	2	74	26
Rains of 0.50 to 1 inch	5	85	15
Rain of 0.10 to 0.50 inch	5	125	−25

With a rainfall of less than half an inch the soil invariably received more than 100 per cent of the precipitation. This indicates that there was some drainage to this land from higher levels and that the above data on run-off represent less than would actually occur on a larger and more representative area. In order to check these results, which were obtained at a single base station, measurements were made to determine the amount of water that penetrated the soil as a result of the rain of 0.89 inch on the night of August 31, 1909, at the base station and at five other points chosen to show the normal run-off for short-grass land during this rain. The results are given in Table VI.

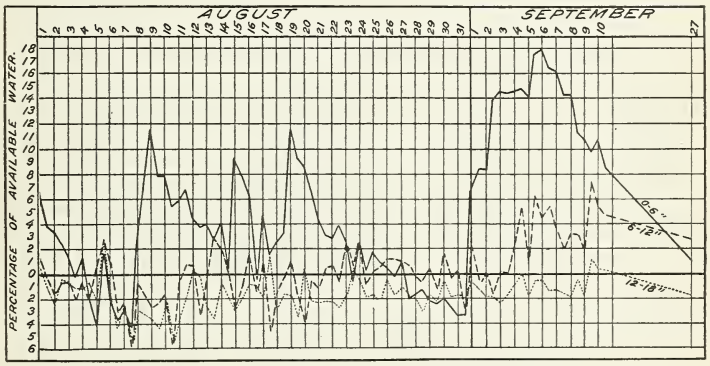

FIG. 6.—Diagram showing the daily available soil moisture, from morning and evening determinations for each 6-inch layer, 0–18 inches, in pure short-grass land, at Akron, Colo., Dry-Land Agriculture Experiment Farm, August and September, 1909.

TABLE VI.—*Run-off and water penetration on short-grass land at Akron, Colo., as a result of 0.89-inch rain August 31, 1909.*

Locality.	Penetration.	Run-off.
	Per cent.	*Per cent.*
Short-grass land at base station	90	10
Average at 5 other points chosen to show normal run-off on pure short-grass land	57	43

The data throughout the season at the base station show that 15 per cent of the rainfall did not enter the soil. Comparisons with the

measurements at five other points show that the run-off at the base station was much below the average for land covered with short grass. The average run-off during this rain for the base station and the five other points was 37 per cent, while the run-off at the base station alone was only 10 per cent. If the seasonal average at the base station was proportionately low, the run-off from the six points must have averaged about one-half of the total rainfall for the same period.

RATE OF WATER LOSS.

The rate of water loss after penetration from short-grass land, estimated from determinations of the water content of the soil and from

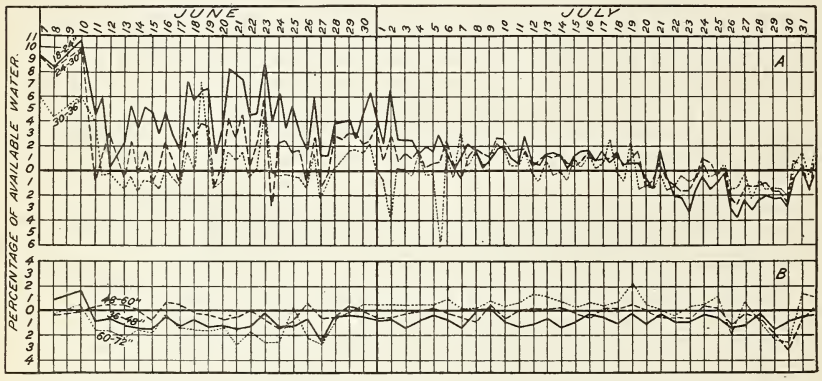

FIG. 7.—Diagrams showing the daily available soil moisture in pure short-grass land, at Akron, Colo., Dry-Land Agriculture Experiment Farm, June and July, 1909: *A*, From morning and evening determinations for each 6-inch layer, 18–36 inches; *B*, from morning determinations for each 12-inch layer, 36–72 inches.

rainfall records, with correction made for run-off during each individual rain, is given in Table VII.

TABLE VII.—*Average daily loss of water per square foot of surface from short-grass land and from free water surface for different periods during the season of growth.*

Date.	Average daily loss, in pounds per square foot of—	
	Short-grass cover.	Water surface.[a]
June 11 to July 7	1.07	1.40
July 10 to July 25	.94	1.56
July 27 to September 10	.42	1.45
June 11 to September 10	.67	1.43

[a] The evaporation data are taken from measurements made under the direction of Dr. L. J. Briggs, of the Physical Laboratory, Bureau of Plant Industry, at the Akron Experiment Farm.

Table VII shows a marked decrease after July 27 in rate of loss of water from land covered with short grass. This is to be explained

largely by the fact that the short grasses were ripe at about that time and transpiration from the plant cover had therefore greatly diminished. These data are especially interesting in showing that transpiration by the short grasses (when in good growing condition) and evaporation from the soil itself exhaust an amount of water equivalent to the entire average rainfall of the period from April to August, inclusive, in about sixty-five days; or exhaust the rainfall of the grain-growing season, April to July, in about fifty-three days.

A comparison of the rate of loss for the two periods, June 11 to July 7, and July 27 to September 10, will throw light upon the question of how much of the water taken out of the soil was due to the transpiration of the short-grass vegetation. During the first period this vegetation was luxuriant, and as a partial consequence the average daily water loss was high, 1.07 pounds per square foot.

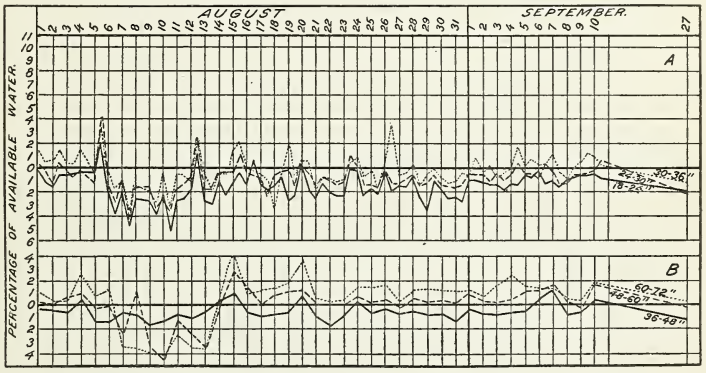

FIG. 8.—Diagrams showing the daily available soil moisture in pure short-grass land, at Akron, Colo., Dry-Land Agriculture Experiment Farm, August and September, 1909: *A*, From morning and evening determinations for each 6-inch layer, 18–36 inches; *B*, from morning determinations for each 12-inch layer, 36–72 inches.

During the last part of the season the short grasses were nearly dormant and the rate of loss was low, 0.42 pound per square foot of surface. This would indicate that considerably more than one-half of the water loss from June 11 to July 25 was due to the transpiration of the short-grass vegetation, while considerably less than half was due to direct evaporation from the soil.

The evaporation data in the right-hand column show that the difference observed in the rate of loss of water from the soil during the two periods was not due to differences in the evaporating power of the air. Reference to the curve of water content of the soil for the first 6 inches (figs. 5 and 6) also shows that the differences in rate of loss of water can not be explained on the basis of differences in the rate of evaporation from the soil due to change in its moisture

content. It seems safe to assume from these data that the transpiration from the short-grass cover during its period of active growth is responsible for considerably more than 50 per cent of the water loss.

Adaptation of Short-Grass Vegetation to Physical Conditions.

The above data show that the conditions on pure short-grass land are such as to limit the depth to which water penetrates, even after heavy rains, to a few inches of the surface soil. The soil is only rarely wet down to a foot or two. Almost the entire root system of the short grasses is limited to the surface 18 inches of soil (fig. 11). The water which actually enters the soil is rapidly lost by the transpiration of the short grasses and by direct evaporation. Deep-rooted

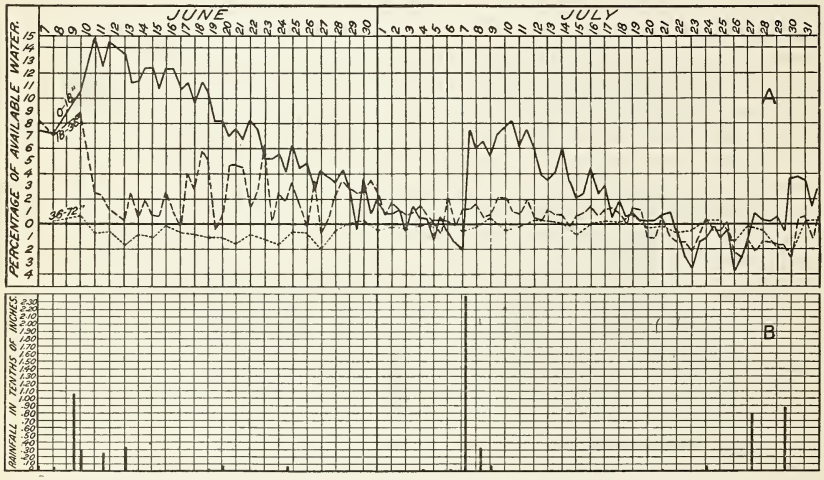

Fig. 9.—Diagrams showing, at Akron, Colo., Dry-Land Agriculture Experiment Farm: *A*, The daily available soil moisture, from morning and evening determinations for layers of soil at depths of 0–18, 18–36, and 36–72 inches, respectively, in pure short-grass land, June and July, 1909; *B*, the daily rainfall from June 7 to July 31, 1909.

plants are not found here for the reason that at greater depths the soil contains no water available for their use.

Short-grass vegetation is also an indicator of a rather short season favorable for growth. In this plant association the growing season is determined, not by the length of period of suitable temperature, but by the length of the period when the soil moisture is sufficient to maintain growth. Grama grass requires approximately sixty days for maturing and often fails to ripen its seed, largely because of insufficient water supply. Buffalo grass usually flowers and fruits early in the season, but when the early season is dry its fruiting may occur at any time during the summer when the water supply is sufficient. It usually blossoms in May, but during the season of 1908 in portions

of the Great Plains did not flower until the latter part of August. The principal adaptation of these grasses to arid conditions seems to lie in their ability to dry out, as do many lichens and mosses, and to revive quickly when water is again supplied. During periods of excessive precipitation both species of grasses grow and fruit luxuriantly. In all probability they would thrive much better under conditions of increased water supply were it not for the fact that under these conditions competition with other species becomes too severe and the short grasses are shut out. These short grasses have a very extensive surface-root system (fig. 11) and are especially adapted to conditions found in the Great Plains region on this type of land. After a slight rain, when only the first few inches of the soil becomes

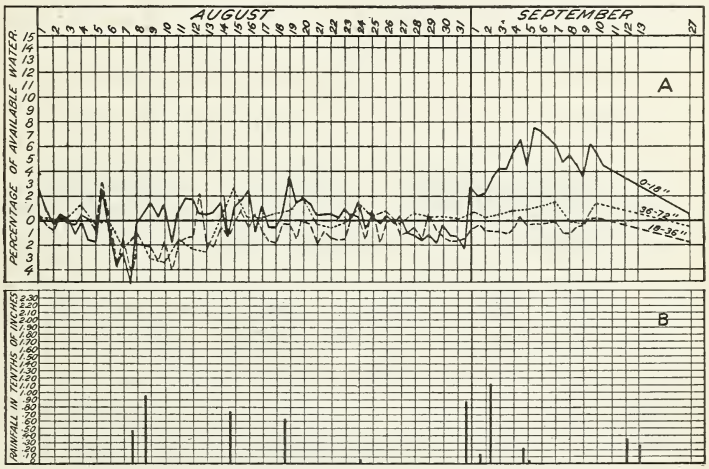

FIG. 10.—Diagrams showing, at Akron, Colo., Dry-Land Agriculture Experiment Farm; *A*, The daily available soil moisture, from morning and evening determinations for layers of soil at depths of 0–18, 18–36, and 36–72 inches, respectively, in pure short-grass land, August and September, 1909; *B*, the daily rainfall, August 1 to September 27, 1909.

wet, these plants are able to absorb water and grow. An enforced rest seems to do them no injury, and with the next shower they are able to continue their growth. Practically the same thing is true of the other species listed (p. 27) as occurring in this short-grass association.

During years of more favorable water supply an increased growth of annuals takes place. These, however, are usually found in the grass mats (fig. 1, p. 17), probably because of the fact that here the moisture conditions are more favorable for germination. The shade afforded by the grasses does not seem to be the deciding factor, since the seeds of many of the Great Plains species germinate better in light than in shade.

Conditions are not very favorable for the development of annuals on the short-grass land. A glance at the curve of available water (figs. 5 and 6) will show that seldom even during a wet year is the water content of the surface 6 inches of the soil high enough for growth during a period of more than a few days at a time. A rapid root development, as well as ability to resist desiccation, are essential to the successful growth of annuals in this environment. They also show remarkable ability to adjust the amount of growth, and hence the time of flowering and fruiting, to the supply of moisture available.

The texture of the soil indicated by short-grass vegetation in this region is a loam, the type of land known locally as "hard land," similar to that called "tight land" in Texas.

FIG. 11.—Sketch showing root systems limited to the surface soil in the grama-buffalo-grass association. Grama grass, *a;* buffalo grass, *b*.

THE EFFECT OF DISTURBING FACTORS.

BREAKING.

The effect of breaking or plowing under the short-grass cover on land that is subsequently abandoned is most marked. It results in starting a succession which requires from twenty to fifty years to complete itself by reestablishing on the area the same vegetation as that turned under. The effect of breaking varies somewhat, and the succession which ensues is determined more largely by the physical conditions than by the composition of the adjacent vegetation. The conditions for seed dispersal by wind are so favorable on the Great Plains that new land can be seeded by plants growing many miles away. The plants which enter this new area are consequently not necessarily those found immediately adjacent to the area. It often happens that a vegetation of Gutierrezia and Artemisia establishes itself upon

plowed land which is in close proximity to an area occupied by the wire-grass association, and vice versa. Many examples of this kind show clearly that the physical conditions are more important in determining what the succession shall be than the relative number of seeds of the different species which are carried into the denuded land. If the vegetation has been derived from the Gutierrezia-Artemisia association (p. 60) and occurs on land exhibiting the environmental conditions that favor that association, breaking will result first in a ruderal or weed stage composed of annuals or short-lived plants. This will be followed by a mixed vegetation in which Gutierrezia (fig. 22, p. 66) or Artemisia (fig. 23, p. 67) predominate or are associated (Pl. II, fig. 1).[a] Short grasses will gradually enter, and the later stage of this succession will show sharply alternating areas of short grass and of Artemisia or Gutierrezia. The complete reestablishment of the short-grass cover will be very slow and will probably not be fully accomplished inside of thirty to fifty years.

If, however, the composition of the short-grass vegetation is more nearly related to that of the wire-grass association (p. 48), and the conditions are therefore more favorable to this association than to the Gutierrezia-Artemisia association, breaking will result in throwing it back into the wire-grass association and the succession will then be as follows: First, an initial ruderal or weed stage[b] not differing essentially from that mentioned above. This stage is only temporary. Either of the two grasses, *Schedonnardus paniculatus* and *Sitanion hystrix*, mark the end of the ruderal stage or the beginning of the permanent stage in this succession. Wire-grass (*Aristida longiseta*, fig. 13, p. 49) will then gradually become

[a] In the northern or northwestern portion of the Great Plains *Artemisia frigida* will probably predominate, while in the southwestern portion *Gutierrezia sarothrae* will predominate. In the central or west-central region, the portion especially considered in this paper, either or both species will become dominant in this stage.

[b] The ruderal stage varies considerably from place to place. It is usually represented by some of the following species:

Dysodia papposa (Vent.) Hitchc.	Amaranthus graecizans L.
Festuca octoflora Walt.	Amaranthus blitoides Wats.
Salsola pestifer A. Nels.	Chenopodium leptophyllum (Moq.) Nutt.
Solanum rostratum Dunal.	Lappula occidentalis (Wats.) Greene.
Malvastrum coccineum (Pursh) Gray.	Chenopodium album L.
Munroa squarrosa (Nutt.) Torr.	Solanum triflorum Nutt.
Plantago purshii R. & S.	Euphorbia glyptosperma Engelm.
Amaranthus retroflexus L.	Leptilon canadense (L.) Brit.

Of these, the tumble weeds, *Amaranthus graecizans* and *Salsola pestifer*, are often the most important species during the first year. Many of these weeds are grazed close to the ground by cattle, and doubtless close grazing greatly reduces the amount of ruderal growth. This aids in the establishment of the grasses by the removal of the taller weeds and also by reducing the rate of water loss from the soil.

established over small alternating areas and the Schedonnardus will gradually die out. Schedonnardus is a short-lived grass, and although it often dominates the early stages of this succession it offers no resistance to the establishment of the taller wire-grass, which crowds it out by overshading it. The condition of the water supply, however, is not such as to support a dense growth of Aristida, and this cover is consequently of a sparse nature and offers an excellent opportunity for the entrance of the short grasses between the scattered bunches (Pl. II, fig. 2). As these short grasses gradually become established they use up more and more of the water supply which would otherwise go to the deeper rooted wire-grass, which, as a result, gradually dies out, leaving a pure short-grass cover. The succession is very slow, requiring from twenty to forty years for completion.

It will be seen from the above discussion that the result of breaking and subsequently abandoning short-grass land is to cause the temporary establishment of a vegetation which is of a deeper rooted type and is normally characteristic of a lighter[a] or less fully disintegrated[b] soil. This is partly due to the fact that the soil has been loosened by the plowing, thus allowing water to enter more readily. Under natural conditions the soil surface in short-grass land is very hard and somewhat puddled. Breaking changes this condition and enables a greater quantity of water to enter the soil. This is especially true of land that has been plowed and subsequently not well worked down. Even in places where the soil had been left undisturbed for eight years after breaking a great difference in water content was noted in the second and third foot as compared with the same depths under unbroken sod. This condition is probably largely due to the fact that the removal of the short-grass cover by breaking decreases the loss of water that is due to absorption by the roots of these grasses. This allows the water to penetrate deeper into the soil, thus establishing a condition more favorable for deep-rooted plants.

GRAZING.

Ordinary grazing does not appreciably modify the short-grass cover. In fact, it seems that grazing somewhat favors the development of pure short-grass cover. Excessive grazing may result in one of two modifications. If the overgrazed portion of the association has recently been derived from the Gutierrezia-Artemisia association (p. 60), and presents soil conditions very similar to those normally found under that association, it will revert to that association.

[a] See wire-grass association, p. 48.

[b] See Gutierrezia-Artemisia association, p. 60.

This is the condition in southern Colorado, northeastern New Mexico, and portions of Texas where the Gutierrezia has again become established on heavily grazed land. The ranchers maintain that the range was once covered with a pure short-grass vegetation, but that grazing, and particularly sheep grazing, has caused the introduction of the Gutierrezia. The vegetation has been disturbed to such an extent that it has reverted to the earlier stage, i. e., the Gutierrezia-Artemisia association, from which in time it will pass again into the short-grass stage if protected from excessive grazing.

If, however, the area of short grass has been derived from the wire-grass association (p. 48), and presents conditions which especially favor that association, excessive grazing will cause it to revert to the wire-grass type of vegetation.

The reversion is made possible by the great reduction in the amount of short grass and the resulting reduction in loss of water from the soil. A smaller percentage of the water is absorbed in the upper layers of the soil and consequently more of it can go to the support of the deeper rooted Gutierrezia or Aristida. Neither Gutierrezia nor Aristida is eaten by animals, and these plants are consequently greatly favored by excessive grazing and the removal of the short grasses with which they are in competition for the soil water.

FIRES.

The effect of fires must be regarded as having been always operative in the Great Plains region. Fires are started by lightning during almost every thunderstorm, and the advent of man has, if anything, tended to check rather than to increase their ravages. The effect of fires on short-grass vegetation in eastern Colorado results in modifying this vegetation very markedly. Grama grass seems to suffer but little, but in places that have been repeatedly burned the buffalo grass is completely killed out. Places of this kind are marked by a pure grama-grass vegetation. Burning also removes all the dead leaves as well as the living ones, and may consequently lead to the impression that the total quantity of plant growth has been much less than is actually the case.

PARASITIC FUNGI.

In places fungus diseases play a part in modifying the short-grass cover. The two common parasites of buffalo grass, *Cercospora seminalis* Ell. and Ev. and *Tilletia buchloëana* Kellerm. and Swingle, do injury chiefly by preventing seed production. They are of minor importance except in their relation to the reseeding of areas from which the plant covering has been removed. Two fungi parasitic

on the grama grass, *Ustilago hieronymi* Schröt. and *Puccinia bartholomewii* Diet., may modify the plant cover to a considerable extent. This is especially true of the Ustilago, which in places reduces the grama to a very thin and scattered cover. Cursory observation might lead to the error of attributing this condition to unfavorable soil conditions. The disease can be recognized by the prominent smut blisters on the leaves, especially noticeable in early spring.

Variations from the Typical Grama-Buffalo-Grass Association and what these Variations Indicate.

Before taking up the more marked variations from the type it will be well to consider some slight modifications in the nature of the plant cover where the vegetation still remains essentially a true short-grass type.

An open-mat cover.

In many places on the Great Plains the plant cover is such as can be designated an "open mat," not more than 15 to 30 per cent of the surface being actually covered with plant growth. The bare places are always irregular in shape and are usually unoccupied, even during periods when annuals develop, for the greater number of the annuals are found within the mats of grama and buffalo grass (fig. 1, p. 17). This open type of short-grass vegetation must be considered as indicating a condition less favorable for plant growth and crop production than where the ground is fully covered. As a rule it is found much more commonly in regions where the rainfall is smaller or less evenly distributed, but it may occur in almost any part of the Great Plains, especially in places where the run-off is very great. The comparative percentages of run-off from ordinary short-grass cover and from open-mat cover as a result of a rainfall of 0.89 inch on the night of August 31, 1909, at Akron, Colo., are given in Table VIII.

Table VIII.—*Comparative water penetration and run-off from ordinary pure short-grass cover and from open-mat cover, as a result of 0.89-inch rain, August 31, 1909, at Akron, Colo.*

Description of cover.	Penetration.	Run-off.
	Per cent.	*Per cent.*
Ordinary pure short-grass cover	62	38
Scattered mats of short grass with a little Schedonnardus	28	72

In all probability a balance is established between the amount of soil water available and the amount of plant growth produced, the growth being, therefore, an indication of the average moisture condition at that particular place. This open-mat phase sometimes

signifies an earlier stage in the development of the true short-grass association. It may be produced by fire (p. 43) or by fungous diseases (p. 43), and when due to these causes does not indicate unfavorable physical conditions for the production of a cultivated crop.

A CLOSE-MAT COVER.

As the other extreme from the open mat we may have a condition where the plant growth is so dense that at first glance the ground appears to be entirely covered. The vegetation affords little opportunity for the entrance of other plants without the displacement of those already established. The close cover as compared with the ordinary short-grass vegetation signifies a soil more uniformly supplied with water and one which, when broken for cultivation, will produce better crops than that occupied by a more open cover. Exceptions should be noted when dense growths of pure buffalo grass are found in depressions where water stands after a rain. Such occurrences are not to be regarded as indicating favorable conditions for crop growth.

These differences in the amount of plant growth unaccompanied by differences in the species represented are of considerable importance as indicators of possible crop production. The appearance of other species usually accompanies more profound differences in the habitat and on this account is of greater indicator value than mere variations in the amount of growth produced. Several modifications of the latter type will now be described.

ARTEMISIA AND GUTIERREZIA ON SHORT-GRASS LAND.

In many places various perennial plants, chief among which are *Artemisia frigida* (fig. 23, p. 67) and *Gutierrezia sarothrae* (fig. 22, p. 66), establish themselves amid the short-grass cover. These plants indicate a condition intermediate between the true grama–buffalo-grass association and the association which is dominated by the perennial species mentioned. As a rule their presence indicates a less thoroughly disintegrated soil, a soil in which water penetrates somewhat deeper than where the pure short grass is found, but not so well adapted for the production of cultivated crops. Care should be exercised, however, in estimating the value of land of this type, since overgrazing or previous breaking will often introduce this type of vegetation on land which would otherwise be occupied by pure short-grass cover. Where this type of vegetation occurs naturally without the intervention of one of the above-mentioned causes, the land is to be regarded as very nearly of the type that is characterized by the Gutierrezia-Artemisia association, which will be discussed later (p. 60).

ASTRAGALUS ON SHORT-GRASS LAND.

The native Leguminosæ, especially *Astragalus crassicarpus*, *A. mollissimus*, and *Aragallus lambertii*, are rather deep rooted, but have a very short season of growth. They are, therefore, not to be regarded as indicating better physical conditions than does the pure short-grass cover, and they do not denote conditions favorable for the production of crops like alfalfa, which requires a long season.

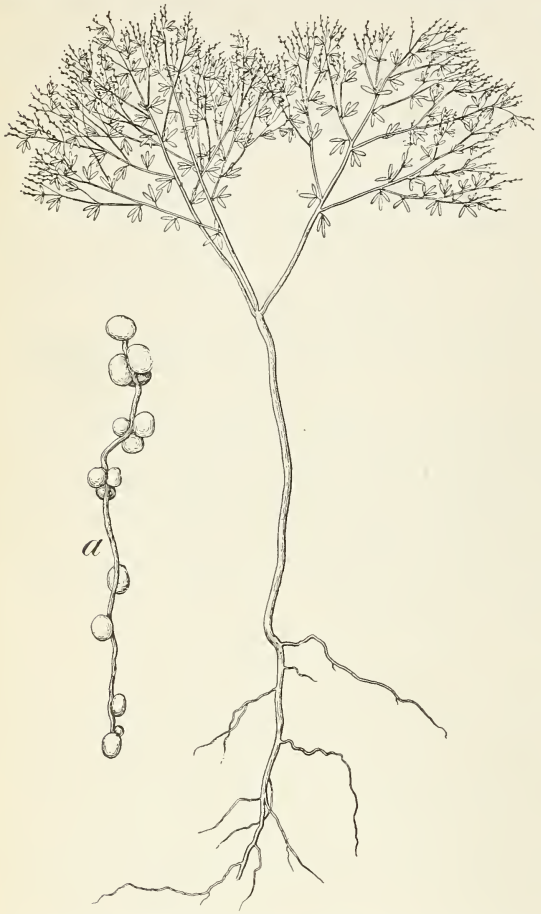

FIG. 12.—Sketch (drawn from photograph) showing a single plant of *Psoralea tenuiflora*. The root extends to a depth of 5 feet and has no surface branches. The rootlet, *a*, showing nodules, which was taken at 3 feet below the soil surface, is about natural size.

PSORALEA ON SHORT-GRASS LAND.[a]

The occurrence on short-grass land of *Psoralea tenuiflora* (fig. 12 and Pl. III, fig. 1), sometimes called "wild alfalfa," and of other deep-rooted plants which require a comparatively long season is to be regarded as an indication of a greater depth of moisture penetration in the soil. Psoralea is always a deep-rooted plant (fig. 14, p. 51), the roots extending to a depth of 4 to 6 feet. As in most of the native legumes of the region, the rootlets are well supplied with nodules for the absorption of nitrogen (fig. 12, *a*). Where this plant is distributed uniformly it indicates either a soil which is more readily penetrated by water than normal short-grass land, or else a place which receives the run-off from an extensive area and which, consequently, is penetrated by more water than that which falls upon it as rain. Accordingly, it indicates a condition more favorable for agricultural purposes than is represented by a pure

[a] *Psoralea tenuiflora* society.

short-grass cover. Where Psoralea plants occur only in small scattered communities, they indicate pockets of looser soil or depressions into which water drains from surrounding areas. Communities of Psoralea in many places mark animal burrows which have been abandoned for some time and which afford ready means for water to penetrate to deeper layers of the soil. The location of areas previously occupied by communities of Psoralea can be detected easily by the condition of the cultivated crop during dry periods. These areas are indicated by the "good spots," and if the land has not been under cultivation for a period sufficient to kill out the Psoralea it will be found still growing amid the crop in the greater number of these areas.

A careful series of comparative measurements of penetration and run-off were made following a rain of 0.89 inch at Akron, Colo., on the night of August 31, 1909, the results of which are shown in Table IX. Care was taken to make the comparative borings on slopes having as nearly as possible the same inclination.

TABLE IX.—*Comparative run-off and water penetration on pure short-grass land and at places where Psoralea is present.*

Description of plant cover.	Penetration.	Run-off.
	Per cent.	*Per cent.*
Pure short-grass land	59	41
Close short-grass cover and Psoralea	176	− 76
Pure short-grass land	81	19
Close short-grass cover and Psoralea	140	− 40
Pure short-grass land	62	38
Close short-grass cover, wire-grass, and Psoralea	137	− 37
Pure short-grass land	90	10
Psoralea clump on short-grass land	274	−174
Pure short-grass land	90	10
Psoralea clump on short-grass land	140	− 40
Pure short-grass land	90	10
Psoralea and wire-grass on short-grass land	214	−114
Pure short-grass land	90	10
One Psoralea plant on short-grass land	226	−126
Average for pure short-grass land	80	20
Average for other places	201	−101

Each comparison was made between spots where Psoralea was present as part of the vegetation and where Psoralea was absent, only a few feet away. These measurements show conclusively that where Psoralea occurs the conditions as to soil moisture are more favorable than where the short grass occurs alone.

WIRE-GRASS ON SHORT-GRASS LAND.[a]

The occurrence of scattered plants of wire-grass (fig. 13, p. 49) amid the short-grass cover (Pl. III, fig. 2), indicates somewhat the

[a] *Aristida longiseta* society.

same conditions as where Psoralea is abundant. Usually, however, wire-grass is not found in the low places where water is likely to stand after heavy rains. It is mainly an indicator of a soil into which water penetrates more readily.[a] The conditions indicated by this vegetative cover are intermediate between those of a pure short-grass vegetation and the typical wire-grass association. Wire-grass is deep rooted and has practically no surface-feeding roots (fig. 14, p. 51). Consequently, it is dependent entirely upon such moisture as occurs at a depth greater than one foot in the soil. It is therefore to be regarded in this region as one of the most reliable plants for indicating favorable agricultural conditions.

WHEAT-GRASS ON SHORT-GRASS LAND.

The wheat-grass association of the Great Plains, characterized by the predominance of western wheat-grass (*Agropyron smithii*), occurs most extensively west of the Missouri River in South Dakota, especially on the adobe soil derived from the Fort Pierre shale. In Colorado it also occupies rather extensive areas of the same kind of soil, although it is not by any means limited to this type. It seems to thrive under a great variety of conditions, penetrates farther into alkali land than do the short grasses, and is equally adapted to resist drought, chiefly by its ability to revive after desiccation. When a sod composed of wheat-grass and short grass is broken and allowed to remain without cultivation the growth of wheat-grass is greatly increased. The wheat-grass plants are not killed by this process and there is a much more abundant water supply available to them as a result of the destruction of the short grasses. In the present stage of these investigations its value as an indicator of the capabilities of crop production remains doubtful.

THE WIRE-GRASS ASSOCIATION.

General Appearance.

Intermediate in character between the short-grass and the bunch-grass types of vegetation, the wire-grass association occurs most commonly on soils of intermediate character which lie between the hard lands and the sand hills. It forms a rather extensive association in certain places in eastern Colorado, being particularly abundant in Washington and Yuma counties. It is found in practically all localities where the short-grass formation and the bunch-grass association

[a] After a rain of 0.89 inch at Akron, Colo., August 31, 1909, the following comparative penetration and run-off were observed: Pure short-grass land, penetration 36 per cent; run-off 64 per cent. Wire-grass amid short-grass cover, penetration 56 per cent; run-off 44 per cent. There was a decided slope where these determinations were made.

meet, and outside of the immediate region under consideration is probably best developed in west-central Kansas and Nebraska.

The wire-grass association is much more varied in general appearance than the grama–buffalo-grass association. The ground is covered by a short-grass mat which is usually not so dense as that of the typical grama–buffalo-grass association. Overtopping this mat are numerous taller plants of many different species, among the more important of which are wire-grass (fig. 13) and Psoralea (fig. 12, p. 46). The wire-grass appears as low tufts which, because of their light silvery color, can be distinguished at once from the so-called bunch-grass which is taller and reddish brown in color. The wire-grass association embraces a much greater number of species than does the grama – buffalo - grass association. Even those phases of the latter which most nearly approach the wire-grass association have nothing like its variety of taller plants. Two of the most important plants, the Psoralea and the bush morning-glory, are tumble-weeds, and leave no trace of their existence when the growth period is past. If the country is fenced the drift of these plants along the fences and roadways will indicate clearly the type of vegetation. The illustration (Pl. I, fig. 2) gives an idea of the general appearance of this association.

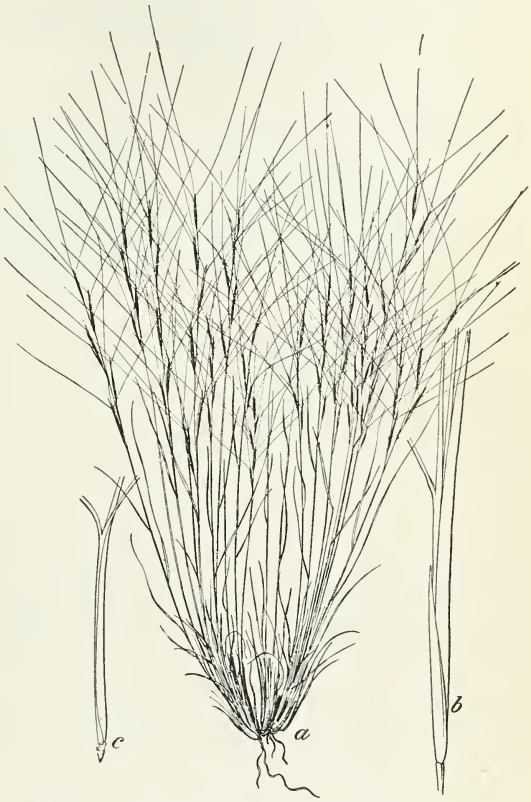

FIG. 13.—Wire-grass (*Aristida longiseta*). Plant, showing habit, *a*; spikelet, *b*; flowering glume, *c*.

BOTANICAL COMPOSITION.

The wire-grass association, being intermediate between the bunch-grass and the grama–buffalo-grass associations, is made up of species

which may be at home in either. The matlike cover is composed largely of the common grama grass (*Bouteloua oligostachya* (Nutt.) Torr., fig. 2, p. 25), although the black grama (*Bouteloua hirsuta* Lag. fig. 17, p. 59) often becomes an important factor. Buffalo grass, on the other hand, is rather rarely found, its place being taken by the black grama. Intermingled with the short-grass mat we find a great many other plants. In addition to the characteristic species, wire-grass (*Aristida longiseta* Steud., fig. 13) and *Psoralea tenuiflora* Pursh (fig. 12, p. 46), many other plants occur of which a few are here listed in order to give a better idea of the composition and general appearance of this association:

Ipomoea leptophylla Torr.
Malvastrum coccineum (Pursh) Gray.
Ratibida columnaris (Sims) D. Don.
Hymenopappus filifolius Hook.
Sideranthus spinulosus (Pursh) Sweet.
Echinocereus viridiflorus Engelm.
Liatris punctata Hook.
Thelesperma gracile (Torr.) Gray.
Erigonum effusum Nutt.
Chrysopsis villosa Nutt.
Lupinus pusillus Pursh.
Schedonnardus paniculatus (Nutt.) Trelease.
Stipa comata Trin. & Rupr.
Sporobolus cryptandrus (Torr.) Gray.
Festuca octoflora Walt.
Carex stenophylla Wahl.

The greater number of these plants are deep-rooted perennials and require a rather long season of growth. In addition to these plants, all the species recorded as occurring in the grama–buffalo-grass association (p. 25) and in the bunch-grass association (p. 54) may be found occasionally in this association.

Physical Conditions Indicated.[a]

The conditions in land occupied by the wire-grass association are such as to permit the growth of both shallow-rooted and deep-rooted plants (fig. 14). The shallow-rooted species are chiefly short grasses which obtain most of their water supply from the first foot of the soil. The texture of the soil is such, however, that water penetrates with comparative rapidity. Approximately all of the rainfall is absorbed, and since the soil is rather light in character, usually a sandy loam, this amount of water is sufficient to penetrate to a depth of several feet. As a result of these conditions this land supports also a deep-rooted type of vegetation which is characterized largely by wire-grass, Psoralea, bush morning-glory, and many other comparatively tall and deep-rooted plants. The wire-grass has practically no surface roots, the roots penetrating deep into the soil and being adapted only to conditions where the soil is moist to a considerable depth. The same is true of Psoralea, bush morning-glory, and the other deep-rooted plants.

[a] The physical conditions of land originally occupied by vegetation of this type when under cultivation are discussed on p. 75.

The presence of short grass, however, indicates a condition unfavorable to the greatest development of the taller, deep-rooted plants. If the water supply were increased the latter would undoubtedly entirely replace the short grass and the vegetation would probably pass over into the bunch-grass association.

The amount of water available below the first foot of soil determines the number of deep-rooted plants which can develop. Since in the wire-grass association this amount is not sufficient to produce a dense growth of such plants, interspaces are left which are occupied by the shallow-rooted, short grasses. The presence of the short

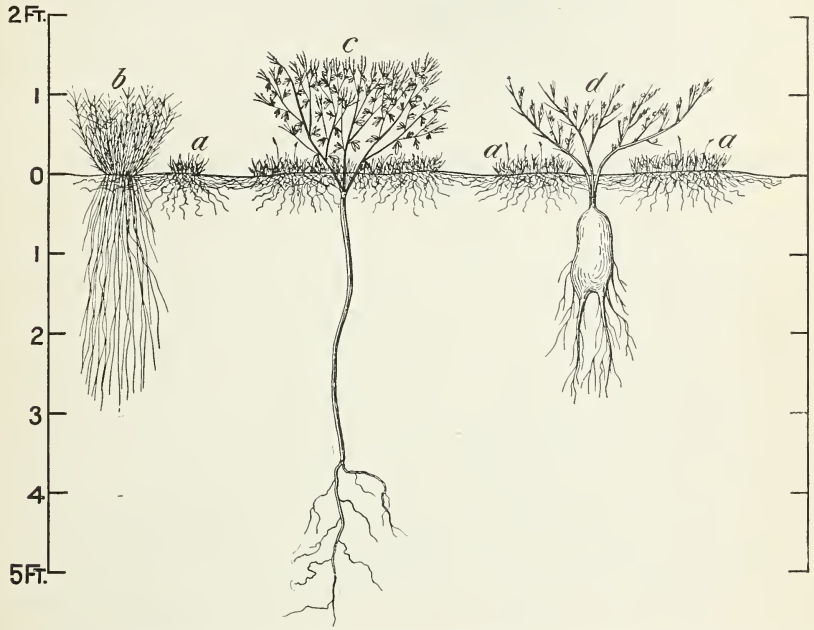

FIG. 14—Sketch showing root distribution in the wire-grass association. Shallow-rooted grama grass, *a;* alternating with deep-rooted wire-grass, *b;* Psoralea, *c;* bush morning-glory, *d*.

grasses further reduces the amount of moisture available to the deeper rooted plants but can not crowd them out entirely because of the fact that in this readily permeable soil the rain water passes below the surface layer before the short grasses can utilize all of it. A condition of unstable equilibrium therefore exists, being more favorable for the deep-rooted plants during wet years and more favorable for the short grasses during dry years.

The conditions indicated by the wire-grass association are undoubtedly the most favorable for crop production of any found in eastern Colorado, since the soil is heavy enough not to blow badly and forms a stable substratum for all types of crops. At the same time it is

pervious enough to enable a very high percentage of the rainfall to enter. The water loss from the soil surface is much less rapid than from the harder lands that are characterized by short-grass vegetation. This is due to the fact that the surface layers, being sandy, dry out very rapidly after a rain and thus soon form a protective dry mulch which checks evaporation. The greater part of the water lost by this soil is through transpiration by the plant cover.

Effect of Disturbing Factors.[a]

Breaking.—When wire-grass vegetation is plowed under and subsequently left without cultivation the result is the introduction of vegetation characteristic of a lighter type of land. The first vegetation is a weed stage which is soon followed by a stage of longer duration in which the grass *Sporobolus cryptandrus* is an important element. But this stage is by no means a pure grass stage, for many other plants also enter. Aristida next appears and at times the bunch-grass (*Andropogon scoparius*). The short grasses, chiefly gramas, are gradually introduced and the typical wire-grass association is reestablished. The succession is more rapid than that on short-grass land and the cycle is probably completed in from twenty to thirty years. One of the most interesting features is the introduction of many plants from the bunch-grass association and even of the true bunch-grass itself (*Andropogon scoparius*, fig. 15, p. 54) in the earliest stages of this succession. Breaking assists the deep-rooted plants to establish themselves by destroying the short-grass cover and allowing the water which would otherwise be absorbed by these grasses to become available to the deeper rooted plants. It is only after continued settling and puddling of the surface soil and the gradual entrance of the short grasses that the old conditions return and the short grasses are able to hold their own with deeper rooted plants, thus establishing the balanced condition which is characteristic of the wire-grass association.

Grazing.—The effect of grazing on land of this type is not very marked because none of the taller plants are eaten to any great extent by cattle and are injured only in so far as they are trampled.

[a] Fungous diseases are at times of some importance in modifying the plant cover. The more important diseases which affect this association are those on the Psoralea-bush morning-glory, wire-grass, and grama grass. Psoralea suffers severely from *Aecidium psoraleae* Pk. and is often thinned out considerably. Another disease which is less destructive is *Parodiella perisporioides* (B. & C.) Speg. The bush morning-glory is also considerably thinned by *Albugo ipomoeae-panduranae* (S.) Swingle. The diseases of wire-grass (*Sorosporium consanguineum* Ell. & Ev.) and grama grass (*Puccinia bartholomewii* Diet.) are much less destructive but may have a slight effect in modifying the plant cover.

Excessive grazing often damages the short-grass cover, thus reducing the loss of water from the upper layers of the soil and enabling more of the deep-rooted plants to enter.

Fires.—Occurring, as they usually do, during the latter part of the summer, fires do not greatly injure old plants of Psoralea and the bush morning-glory, but the seeds are destroyed and propagation is thus checked. The wire-grass, however, is badly burned. Where fires are very frequent their tendency is to convert this type of vegetation into a pure short-grass cover.

Variations from the Type of the Wire-Grass Association.

Being intermediate between the pure bunch-grass and the pure short-grass types, vegetation of the wire-grass association is found varying now in the direction of the one and now in the direction of the other. When it approaches a pure short-grass cover one or the other of the following conditions will be found to exist: (1) Either the land has become so impervious as to be in almost the same condition as the short-grass land, so that but few of the deep-rooted plants can obtain sufficient water for their requirements, or else (2) fires have completely destroyed the taller, deeper rooted plants. The evidence of fires is so unmistakable, however, that one can not easily be misled as regards this factor, the effect of which is, moreover, temporary. In an area of this type in which the deeper rooted plants have died out the old roots found in the deeper soil layers are a positive proof that the land was once occupied by the wire-grass association. Wherever the vegetation approaches a pure short-grass type owing to the impervious nature of the soil the vegetation and physical environment may be identical with that already described in the grama–buffalo-grass association under the headings "Wire-grass on short-grass land" (p. 47) and "Psoralea on short-grass land" (p. 46).

Wherever characteristic plants of the bunch-grass or of the sand-hills mixed association, such as sand sage (*Artemisia filifolia*, fig. 20, p. 64) and bunch-grass (*Andropogon scoparius*, fig. 15, p. 54), occur in the wire-grass association the indication is that the land is lighter in texture and is very similar to that characterized by those associations.

Sometimes the plant cover is very sparse, leaving a considerable percentage of the surface of the ground bare, although many different species of plants are present. This aspect of the wire-grass association is to be regarded as indicating conditions less favorable for agricultural purposes than where the vegetative cover is close and more or less uniform.

THE BUNCH-GRASS ASSOCIATION.

General Appearance.

The most extensive association on the sand hills of eastern Colorado is designated by the name of bunch-grass, which aptly describes its general appearance. As usually found in eastern Colorado, the clumps of bunch-grass are somewhat scattered, the spaces between being occupied by other plants. The general appearance of the vegetation is well shown in the accompanying illustration (Pl. IV, fig. 1). The considerable difference in the appearance of this association in different places is due largely to variation in the amount of bunch-grass present, but it can be recognized at any time of the year by the reddish-brown color of this grass. The vegetation appears much darker in color when looking against the wind than when looking in the direction the wind is blowing. In places where sand sage grows with the bunch-grass there may be a considerable variation of color.

FIG. 15.—Bunch-grass (*Andropogon scoparius*), showing habit of growth, *a;* single plant, *b;* and details of spikelet, *c, d, e, f.*

The association in eastern Colorado is by no means as open as is commonly the case in Nebraska. The soil surface is occasionally well covered by an almost pure, close stand of bunch-grass, but more often by this grass mixed with other tall grasses and with short grasses occupying the interspaces. The soil is held so firmly that there is practically no blowing in land occupied by this association.

Botanical Composition.

The botanical composition of the bunch-grass association is somewhat varied. The plant which chiefly characterizes it is the bunch-grass (*Andropogon scoparius* Michx., fig. 15), but this grass is

accompanied by a great many other species, of which the following are some of the most important:

Bouteloua hirsuta Lag.	Panicum virgatum L.
Andropogon hallii Hack.	Psoralea tenuiflora Pursh.
Calamovilfa longifolia (Hook.) Hack.	Bouteloua oligostachya (Nutt.) Torr.
Aristida longiseta Steud.	Artemisia filifolia Torr.

The bunch-grass often forms a dense growth, leaving room for few other plants. But usually the bunches are scattered (Pl. IV, fig. 1), and the interspaces are occupied by the other species above listed. As the bunch-grass becomes less dominant, conditions approach more and more nearly those found in the sand-hills mixed association (p. 58). In addition to the above all the species enumerated under the wire-grass association (p. 50) and the sand-hills mixed association may occur. To the description of the latter association especially, the reader is referred for a more complete list (p. 58) of plants that occur in the bunch-grass association.

Physical Conditions Indicated.

Where bunch-grass occurs we find a soil which contains moisture to a considerable depth. The bunch-grass itself is a deep-rooted plant, poorly adapted to absorb water from the surface soil. It is, accordingly, most commonly found on land where the bulk of the water supply lies below the first foot of soil. The greater number of the other plants found in this association have a similar root habit, but it also embraces many plants which utilize the water from the surface layers (fig. 16). Among the most important of these are the grama grasses, which here find a footing only in places not already occupied by the bunch-grass or other taller plants. All rainfall received by this type of land enters the soil and there is no run-off. The bunch-grass association in eastern Colorado occurs on a sandy soil [a] from which evaporation is relatively slow, owing to the rapid establishment of a surface mulch of dry soil after a rain. Where the water supply is sufficient an almost pure, dense cover of bunch-grass

[a] With few exceptions the bunch-grass is limited in eastern Colorado to the sand hills. The exceptions are interesting. On banks where the soil is slowly falling down and where the water accordingly penetrates to considerable depths bunch-grass dominates even when the soil is a heavy loam. In the region of Bellefourche, S. Dak., bunch-grass was found on soil derived from the Fort Pierre shale, in places where the moisture conditions were especially favorable. Occasional clumps are found in heavy land in low places in eastern Colorado, where water stands for a short time after a rain. This species occurs quite commonly on clay or silt loam ridges and "breaks." In such places the soil is loose and is wearing away rapidly, the vegetation is scattered, and the conditions for water penetration are unusually favorable. It also occurs quite commonly on the gravelly soils near the mountains. Farther east, where the moisture conditions are more favorable, it grows on a loam soil (pp. 12 and 24).

develops, but where the supply is less abundant the bunches are more scattered and there is a greater growth of short grass in the spaces between. The soil characterized by this association is not especially rich in plant food, but affords a better water supply than any other in the region.

Effect of Disturbing Factors.[a]

Breaking.—In eastern Colorado bunch-grass grows on a sandy soil. When such land is broken by plowing considerable blowing is likely

Fig. 16.—Sketch showing root distribution in the bunch-grass association. Bunch-grass, *a;* Psoralea, *b;* wire-grass, *c;* black grama, *d.*

to result. In fact, it often happens that a blow-out is established which will not be completely revegetated for very many years (Pl. VI, fig. 1). This, however, is not the most frequent course of events. Usually the land becomes covered after plowing with a growth of annual tumbleweeds, various Compositæ, amaranths, and the grass

[a] Fungous diseases have little modifying effect on this association. *Puccinia andropogonis* S. occurs on *Andropogon hallii* and rarely on *A. scoparius*, but seems to do little damage. Psoralea, wire-grass, and bush morning-glory are sometimes badly parasitized. (See footnote, p. 52.)

Sporobolus cryptandrus. Plants from the sand-hills mixed association rapidly enter and the bunch-grass soon reestablishes itself. In general, we may state that the vegetation which follows breaking land of this character, when it is left without cultivation, corresponds to an historically earlier stage in the development of this association. If a blow-out occurs, the complete reestablishment of the bunch-grass may possibly require more than a century. If the more usual course is followed, the vegetation will in all probability return to the bunch-grass type in less than twenty years.

Grazing and fires.—Grazing alone does not materially modify this association when once well established. This is due to the fact that cattle do not eat the old bunch-grass. Fire, however, is a very important factor. The great mass of dry matter produced offers favorable conditions for the spreading of fires, which are often started by lightning. Burning injures the bunch-grass to such an extent that it does not fully recover for several years. The new growth is eaten by cattle, and as a result conditions are brought about which are favorable for the entrance of the short grasses. Under conditions of frequent fires and excessive grazing the short grasses become established on land which otherwise would be occupied by bunch-grass. This is a common condition inside the fire breaks along the railroads, in which places fires are frequent. Here bunch-grass is entirely replaced by short grasses, although the land just outside the breaks, where fires are much less frequent, may be completely dominated by bunch-grass.

Variations from the Type of the Bunch-Grass Association.

Wherever the composition of the vegetation approaches very closely that of the wire-grass association (p. 48), it indicates a somewhat heavier type of soil, one which is by no means so likely to blow and yet retains its ability to take up water rapidly and to support the growth of deep-rooted plants. This land is, consequently, much more desirable for agricultural purposes than that of the pure bunch-grass type.

Wherever the growth of bunch-grass is unusually pure and dense, forming a close cover, it indicates a condition of favorable water supply, combined with rather high fertility, and is probably the most favorable type of bunch-grass land for general purposes of agriculture next to the variation toward the wire-grass association. The presence of the sand sage (*Artemisia filifolia*, fig. 20) and of the taller grasses (figs. 18 and 19) is very often associated with the occurrence of a more sandy soil and of conditions approaching those indicated by the sand-hills mixed association, which is discussed in the following section.

THE SAND-HILLS MIXED ASSOCIATION.

GENERAL APPEARANCE.

The great amount of variation found in the sand-hills mixed association (Pl. V, fig. 1) makes its general appearance rather difficult to describe. In general, it may be said to be dominated by taller growing grasses which often form large clumps several feet in diameter and which do not have the bunch-grass habit. Alternating with these are areas which are occupied by the grama grasses, *Bouteloua hirsuta* (fig. 17) being the most important, and by a great variety of taller plants other than grasses. The most characteristic feature of this vegetation is the presence of large and sharply alternating communities of the coarse-stemmed grasses, *Calamovilfa longifolia* (fig. 18) and *Andropogon hallii* (fig. 19), locally known, respectively, as "sand-grass" and "big bluestem."

BOTANICAL COMPOSITION.

The sand-hills mixed association shows great variation in botanical composition, as well as in general appearance. The following are the most important species:

Bouteloua hirsuta Lag.
Andropogon hallii Hack.
Calamovilfa longifolia (Hook.) Hack.
Artemisia filifolia Torr.
Aristida longiseta Steud.
Bouteloua oligostachya (Nutt.) Torr.
Psoralea tenuiflora Pursh.

Next to Calamovilfa and *Andropogon hallii*, sand sage (*Artemisia filifolia*, fig. 20) is the most noticeable plant. Bunch-grass (*Andropogon scoparius*) often occurs in this association, but whenever it becomes abundant the vegetation passes over to the bunch-grass association, which represents a much more stable type of vegetation.

The more open the vegetation the greater the number of species which are found. Almost everywhere there are species of secondary importance in great variety. The following list includes some of the more numerous of these plants:

Panicum virgatum L.
Ipomoea leptophylla Torr.
Yucca glauca Nutt.
Artemisia canadensis Michx.
Andropogon scoparius Michx.
Thelesperma gracile (Torr.) Gray.
Sorghastrum nutans (L.) Nash.
Chrysopsis villosa Nutt.
Bouteloua curtipendula (Michx.) Torr.
Liatris punctata Hook.
Cyperus bushii Brit.
Sideranthus spinulosus (Pursh) Sweet.
Ratibida columnaris (Sims) D. Don.
Artemisia gnaphalodes Torr. & Gray.
Petalostemum purpureum (Vent.) Rydb.
Eriogonum annuum Nutt.
Eriogonum effusum Nutt.
Sporobolus cryptandrus (Torr.) Gray.
Amorpha canescens Pursh.
Meriolix serrulata (Nutt.) Walp.
Stipa comata Trin. & Rupr.
Ambrosia psilostachya DC.
Hymenopappus filifolius Hook.
Evolvulus argenteus Pursh.
Helianthus petiolaris Nutt.
Tradescantia occidentalis Brit.
Andropogon furcatus Muhl.

PHYSICAL CONDITIONS INDICATED.

The soil on which the sand-hills mixed association occurs is usually a purer sand than that characterized by the bunch-grass association. It is a soil into which all of the rainfall penetrates, and in its water relations it is much the same as bunch-grass land. The conditions are, therefore, favorable for deep-rooted plants (fig. 21, p. 65). The danger of blowing is even greater here than on bunch-grass land.

EFFECT OF DISTURBING FACTORS.

Breaking or plowing occasionally results in establishing blow-out conditions. When blow-outs do not develop, following breaking, and the land is left uncultivated the vegetation returns rapidly to the sand-hills mixed type. In the early stages of revegetation typical blow-out grasses (p. 60) quite commonly appear.

Fire and grazing are important factors in changing this type of vegetation. Grazing alone can alter this association much more than it can the bunch-grass vegetation, from the fact that all the important grasses are eaten by stock. One of the most marked changes thus produced is that the taller grasses are eaten down close to the ground, permitting the short grasses *Bouteloua hirsuta* (fig. 17) and *B. oligostachya* (fig. 2, p. 25) to develop. Grazing is especially favorable to the sand sage (*Artemisia filifolia*, fig. 20), which is not eaten by

FIG. 17.—Black grama (*Bouteloua hirsuta*). Plant, showing habit, *a;* flowering spikes, *b;* empty glumes, *c;* perfect and imperfect flowers, *d;* flowering glume, *e*.

cattle, and upon the removal of the tall grasses and the consequent increase of moisture available in the deeper layers of the soil grows into unusually large plants. In this condition the appearance of the association is entirely altered (Pl. V, fig. 2).

VARIATIONS FROM THE TYPE OF THE SAND-HILLS MIXED ASSOCIATION.

This type varies on the one hand into the bunch-grass association and on the other into the blow-out association. (See below.) Wherever the natural vegetation is thin there is especial danger of blow-outs when the land is plowed, and in such places the plant cover should never be disturbed. Wherever the vegetation is dense this land offers fairly good conditions for crop production. The presence of a luxuriant growth of sand sage (Pl. V, fig. 2) with short grasses forming a close mat between the bushes also indicates conditions which are relatively favorable for crop production.

ASSOCIATIONS IN EASTERN COLORADO INDICATING NONAGRICULTURAL LAND.

THE BLOW-OUT ASSOCIATION.

Some of the most important plants that colonize blow-outs[a] (Pl. VI, fig. 1) are:

Redfieldia flexuosa (Thurb.) Vasey.
Psoralea lanceolata Pursh.
Muhlenbergia pungens Thurb.
Petalostemum villosum Nutt.

Any one of these sand-binding plants may form an almost pure cover or they may all occur in the same blow-out. These plants are usually followed by *Calamovilfa longifolia* (Hook.) Hack. (fig. 18), *Andropogon hallii* Hack. (fig. 19, p. 63), and many other species from the sand-hills mixed association.

The soil on which this association occurs is a pure, coarse sand. Below the dry surface mulch of 1 or 2 inches the soil is usually well supplied with moisture, the conditions for the conservation of a limited moisture supply being even more favorable than on summer-tilled land of a heavier type. When once a plant is established, conditions are favorable for growth. All of the plants here mentioned spread rapidly by rootstocks and runners and have very extensive root systems.

THE GUTIERREZIA-ARTEMISIA ASSOCIATION.

The vegetation of the Gutierrezia-Artemisia association is of an open, scattered type, leaving much of the soil surface bare. It is

[a] A typical blow-out is a large, crater-like area, often several hundred feet across, usually located in the top or side of a sand hill. The term is here used for all areas where sand is not held by vegetation and is consequently moving rapidly as a result of wind action.

usually found where the surface of the ground consists of partly disintegrated rock (Pl. VI, fig. 2), and varies considerably in different portions of the Great Plains region. In the South it is characterized chiefly by *Gutierrezia sarothrae* (Pursh) B. & R. (fig. 22),[a] while farther north *Artemisia frigida* Willd. (fig. 23) becomes predominant. Except in the very earliest stages of the development of the association, *Bouteloua oligostachya* (fig. 2, p. 25) is always one of the most important elements. In the central regions the Artemisia and the Gutierrezia meet on almost equal terms. This vegetation indicates areas where water penetrates somewhat better than it does on pure short-grass land, but where, owing to the fact that the rock is not fully disintegrated into soil, the establishment of vegetation is taking place rather slowly. Such land is, of course, without agricultural value. This association includes most of the stages in succession from the first plants which appear after the disintegration of the rock commences to the final establishment of the pure short-grass cover. In its most

FIG. 18.—Sand-grass (*Calamovilfa longifolia*). Clump, showing habit, *a;* single plant, *b;* spikelet, *c;* spikelet with empty glumes removed, *d*.

[a] An attempt to recognize in the field the many species that have been described in this genus leads to the conclusion that in some cases individual plants of different ages have been described as different species, and that some of these so-called species are produced merely by the operation of drought or of wet weather. On this account it seems best to follow Coulter and Nelson (New Manual of Rocky Mountain Botany, 1909, p. 489), who state concerning the forms most commonly found on the Great Plains that "It were better perhaps to consider them forms of this (*Gutierrezia sarothrae* (Pursh) B. & R.), as did Doctor Gray."

typical aspect it is characterized by the dominance of the two species for which it is named. A great many other plants are found in this association, among which are the following:

Actinella simplex A. Nels.
Eriogonum effusum Nutt.
Hymenoppapus filifolius Hook.
Eriogonum alatum Torr.
Paronychia jamesii T. & G.
Meriolix serrulata (Nutt.) Walp.
Psoralea tenuiflora Pursh.
Sideranthus spinulosus (Pursh) Sweet.
Chrysopsis villosa Nutt.
Eriogonum jamesii Benth.
Bouteloua curtipendula (Michx.) Torr.
Artemisia canadensis Michx.
Koeleria cristata (L.) Pers.
Lesquerella argentea (Pursh) MacM.
Astragalus sericoleucus Gray.
Grindelia squarrosa (Pursh) Dunal.
Oreocarya thyrsiflora Greene.
Actinella fastigiata (Greene) A. Nels.
Lithospermum angustifolium Michx.
Artemisia tridentata Nutt.
Malvastrum coccineum (Pursh) Gray.
Plantago purshii R. & S.
Opuntia polyacantha Haw.
Mentzelia nuda (Pursh) T. & G.
Petalostemum purpureum (Vent.) Rydb.
Yucca glauca Nutt.

THE LICHEN FORMATION.

On the Great Plains plants of the lichen formation occur only on rock outcrops and rock fragments. Their distribution is, therefore, limited. In its later stages this formation often passes into the Gutierrezia-Artemisia association and frequently persists even after the establishment of the short grasses. While this formation varies considerably in the species present in different portions of the Great Plains, in its appearance, at least, it is practically uniform. Important species in this lichen covering are:

Rinodina oreina (Ach.) Mass.
Lecanora calcarea (L.) Nyl.
Parmelia conspersa (Ehrh.) Ach.
Lecanora subfusca allophana Ach.

RELATIONSHIP OF THE DIFFERENT ASSOCIATIONS.

NATURAL SUCCESSIONS.[a]

All the associations thus far described are stages in one or the other of two great successions of vegetation. One of these begins with the appearance of lichens on the rock outcrops and ends with the full establishment of a pure short-grass cover. The other, beginning with bare sand on which plants of the blow-out association first appear, leads to the establishment of the sand-hills mixed association or of the bunch-grass association, and from either of these may pass on through the wire-grass association to a pure short-grass cover.

In the first succession the lichens become established on disintegrating rocks. As soon as the rock is broken down into finer particles

[a] See footnote, p. 19, for a definition of the term "succession."

and soil has been formed, plants of the Gutierrezia-Artemisia association (p. 60 and Pl. VI, fig. 2) begin to establish themselves, and gradually the land is occupied by this association. The presence of many rock fragments on the surface of the soil brings about a condition favorable to the downward percolation of water and unfavorable to its loss by evaporation. The greater number of the characteristic plants of this association are without surface-feeding roots, yet the conditions are favorable for the growth of the short grasses, and grama grass gradually becomes established. This shallow-rooted grass takes up much of the water in the surface layers of the soil, and consequently diminishes the supply which can penetrate to a depth where it becomes available to the deeper rooted plants of the Gutierrezia-Artemisia association. In the course of time the rock fragments become thoroughly disintegrated, forming a true soil, and the short grasses become dominant; the deeper rooted plants are slowly killed out and the pure short-grass vegetation is established.

FIG. 19.—Big bluestem (*Andropogon hallii*). Clump, showing habit of growth, *a*; single plant, *b*; details of spikelet, *c*, *d*, *e*, *f*.

The succession which begins with the blow-out is much more complex. The moving soil is first held by plants which constitute the blow-out association (p. 60). This gives way to the sand-hills mixed association (p. 58 and Pl. V, fig. 1) without the intervention of any factors other than the appearance of the plants themselves and the resulting increased stability of the soil. The vegetation may remain

in this condition for a long period or it may pass over into one of the modifications of the sand-hills mixed association (p. 60 and Pl. V, fig. 2), or it may gradually give place to the bunch-grass association (p. 54 and Pl. IV, fig. 1).

It is probable that without the intervention of fires or of grazing the succession would usually end at this point. But the intervention of these factors is likely to produce still further changes. The effect of frequent fires may in time change the vegetation from bunch-grass to short grass, or this result may be accomplished through the influence of grazing. The transition often takes place through the intermediate wire-grass association (p. 48 and Pl. I, fig. 2).

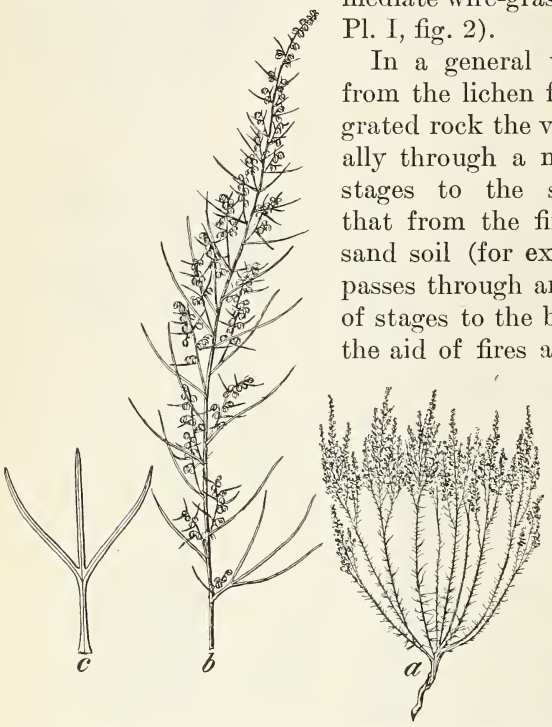

FIG. 20.—Sand-sage (*Artemisia filifolia*). Single plant, *a*; flowering branch, *b*; leaf, *c*.

In a general way we may say that from the lichen formation on undisintegrated rock the vegetation passes gradually through a number of well-marked stages to the short-grass cover, and that from the first vegetation on bare sand soil (for example, in blow-outs) it passes through an even greater number of stages to the bunch-grass cover. By the aid of fires and grazing this bunch-grass cover in time often passes over gradually to the pure short-grass type.

Still another succession should be mentioned. Where the rocks which disintegrate are sandstone the vegetation which establishes itself after the lichen formation is not the Gutierrezia-Artemisia association, but a wire-grass or a bunch-grass vegetation. If the soil formed is exceedingly sandy, the bunch-grass vegetation may become permanently established. If, however, the soil is less sandy, wire-grass vegetation will first become established, and this will be followed gradually by pure short-grass cover.

We see, then, that short-grass vegetation represents the final stage of three different successions: First, that beginning with the lichen

formation and passing through the Gutierrezia-Artemisia association; second, that beginning with the lichen formation and passing through the bunch-grass and the wire-grass associations; third, that beginning with the blow-out and passing through the sand-hills mixed asso-

FIG. 21.—Sketch showing root distribution in the sand-hills mixed association. Sand-grass, *a;* sand sage, *b;* bunch-grass, *c;* big bluestem, *d;* bush morning-glory, *e;* wire-grass, *f;* black grama, *g*.

ciation, and, with the aid of fires or of grazing, through the bunch-grass and the wire-grass associations.

SUCCESSIONS DUE TO THE INTERVENTION OF MAN.[a]

The successions due to the intervention of man are of importance in this connection from two points of view. In the first place they show to what extent damage is done to the native pasture or range

[a] See footnote, p. 19.

by breaking.[a] In the second place they throw much light upon the way in which the natural successions must have taken place, and hence their study has contributed greatly to a more complete understanding of the present structure of the different associations and what they indicate as to environmental conditions.

Wherever short-grass land is broken (p. 40) and then abandoned it is first covered by a growth of weeds, after which the type of vegetation that immediately preceded the short grass in this particular place regains possession. If, for example, we break short-grass land which has been derived from the Gutierrezia-Artemisia association and consequently offers conditions favorable to that association the land will become occupied by the latter association (Pl. II, fig. 1). The Gutierrezia-Artemisia vegetation will in turn gradually give way to the short grasses, which will be fully reestablished within a period of thirty to fifty years. An area of short-grass land in which the physical conditions approach more nearly those of wire-grass land, if broken, will be possessed after the preliminary weed stage by plants of the wire-grass association (Pl. II, fig. 2), and will then gradually return to the short grasses, the time required being twenty to forty years.

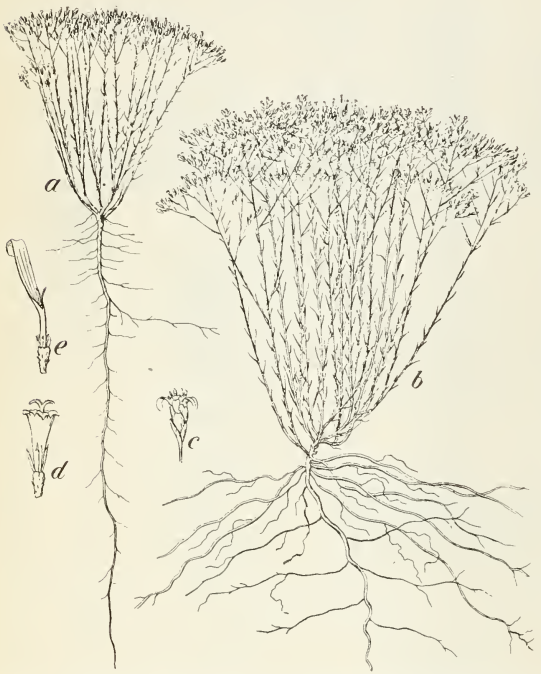

FIG. 22.—*Gutierrezia sarothrae*. Young plant showing deep taproot, *a;* old plant showing better development of lateral roots, *b;* flower head, *c;* disk flower, *d;* ray flower, *e*.

Breaking done on wire-grass land (p. 52) will result in the establishment of a vegetation such as usually characterizes a still lighter type of soil. Many plants from the bunch-grass and the sand-hills mixed associations enter, and in the early stages of this succession bunch-grass itself quite generally occurs. The vegetation will ordinarily return to the wire-grass type in fifteen to thirty years.

[a] If wheat-grass is abundant, breaking often improves the range, but as a rule the range is damaged.

Wherever land characterized by the bunch-grass (p. 54) or the sand-hills mixed associations (p. 58) is broken a blow-out (p. 60 and Pl. VI, fig. 1) may result. This, however, is unusual, although there is great danger if the land is plowed in the fall of the year. Usually the weed stage is most prominent the first year or so, but the native grasses soon regain possession and the succession is completed in a much shorter time than on the heavier types of land.

It will thus be seen that when the vegetation of each of the plant associations is destroyed by breaking it will be followed, after the weed stage, by vegetation characteristic of a lighter type of soil, and also that this vegetation is that characteristic of an earlier stage in the natural succession.

A knowledge of the conditions indicated by these secondary successions which result from breaking is a useful guide in estimating the comparative value of land. For example, short-grass land which when broken reverts to wire-grass should be regarded as much more favorable for agricultural purposes than short-grass land which when broken becomes occupied by Gutierrezia and Artemisia.

FIG. 23.—*Artemisia frigida*. Plant, showing habit, *a;* flower head, *b;* single flower, *c;* leaf, *d*.

PLANT COMPETITION AND THE REASONS FOR THE SUCCESSIONS.

The successions brought about by breaking are probably due entirely to the changed physical conditions. The destruction of the

entire surface vegetation by plowing brings about a condition which is much more favorable for the storage of water in the soil than previously existed. Repeated observations in the field show that after a rain the water penetrates much deeper on land that has been broken than on that covered by the undisturbed native sod. This increase in the depth of penetration is brought about partly as a result of the great reduction in the quantity of plant growth and the consequent higher water content of the soil previous to the rain and partly as a result of decreased run-off on the broken land as compared with the native sod.

Breaking destroys the vegetation almost entirely, thus leaving the area open for the entrance of new plants. Naturally, the annual weeds, with their exceptional ability to seed new land and to grow rapidly at almost any period of the year when temperature and water content are favorable, are first to appear. The species which may enter into this stage are so numerous and their appearance is so dependent upon the chances of a supply of seed being near at hand that this stage of the succession has been passed over with very little discussion.[a]

If after short grass is turned under the Gutierrezia-Artemisia type of vegetation becomes established it is probable that in the deeper layers of the soil conditions are more favorable for the growth of deep-rooted plants than they were previous to breaking. The subsequent reestablishment of the short grasses on such land and the resulting disappearance of the Gutierrezia and Artemisia are likewise results of changes in the physical condition. The surface soil gradually becomes hard again and somewhat puddled, resulting in decreased water penetration and increased run-off. Measurement of the rate of penetration shows a great increase when the surface of soil of this character is loosened or removed. Another condition which is of great importance here is the direct competition for water between the short grasses and the deeper rooted plants of the Gutierrezia-Artemisia association. Many of the latter, such as Actinella, Eriogonum, etc., have practically no surface roots. As the short grasses gradually enter, their shallow roots have the first chance at the moisture, which after a rain is held for some time in the surface layers of the soil and passes but slowly to deeper layers (p. 33).

The younger plants of Gutierrezia have a very deep tap root and almost no lateral roots (fig. 22, *a*, p. 66). The short grasses are consequently able to kill out this plant by consuming the available water before it can reach the roots of the Gutierrezia. This condition comes about gradually, however, and many of the older Gutierrezia plants will be found to maintain themselves for a long

[a] See footnote, p. 41.

period in the short-grass cover. But an examination of the roots of such plants will show that the root habit has become greatly changed (fig. 22, *b*). Many lateral roots have developed which feed largely in the surface layers of the soil and are in this way able to compete with the roots of the short grasses. The long season required for Gutierrezia to complete its development and ripen seed is probably one of the reasons why, notwithstanding its ability to modify its root system, it does not succeed better in competition with the short grasses.

When wire-grass vegetation becomes established upon short-grass land that has been broken the plants of this association are likely to dominate for a number of years. But the cover is never very close, and in the interspaces the short grasses soon become established. Wire-grass is deep rooted and feeds in layers of the soil lower than those which sustain the short grasses. The wire-grass is gradually shut out by the short grasses, which absorb the water in the surface layers, leaving little or none for deeper rooted plants. It is clear that with a limited water supply the short grasses, having roots which completely occupy the surface soil, are able to drive out the deeper rooted plants with which they come into competition.

Wire-grass land affords a good illustration of a balanced condition—a condition of continual stress between the short grasses and the deeper rooted plants (fig. 14, p. 51). The fact that water is available in the deeper layers of the soil is demonstrated by the presence of many deep-rooted plants on this land, and it might be supposed that under these conditions bunch-grass would take possession. But in this connection we should consider that bunch-grass requires a long season, approximately one hundred and fifteen days, to complete its growth, while wire-grass requires only about forty days to ripen seed. Even *Psoralea tenuiflora* (fig. 12, p. 46), which is one of the long-season plants of the wire-grass association, requires only about eighty days. In the wire-grass areas there is less water in the deeper layers than on bunch-grass land, and it is in all probability exhausted much earlier in the season. The plants of short-grass land are, as a rule, short-season plants, grama grass requiring sixty days to mature, while buffalo grass requires only about thirty-six days. The plants of the wire grass association are intermediate in length of season. Bunch-grass and many of the species associated with it require a long growing period, and a sufficient water supply is necessary throughout the summer.

The behavior of the native vegetation indicates clearly that the conditions favorable for growth on short-grass land last for only a comparatively short season, beginning with the spring rains and extending to about the middle of summer. The more important

plants of this association can mature in sixty days or less and many of them in less than forty days. On wire-grass land the season is somewhat longer, while on bunch-grass land it is almost twice as long, the principal species requiring considerably over one hundred days to mature seed.

The physical conditions on bunch-grass land are favorable for the development of wire-grass and of the short grasses as well as of bunch-grass. The two former are kept down by direct competition, by being shaded by the taller bunch-grass. The physical conditions on wire-grass land are favorable for the short grasses, and these are kept down in the same way by the wire-grass. On the other hand, the physical conditions encountered on the short-grass land are decidedly unfavorable for bunch-grass and often for wire-grass as well.

Grazing and fires bring about conditions which are especially interesting from the standpoint of plant competition. Working together they keep down the bunch-grass and similar tall-growing species, thus allowing the short grasses to maintain themselves notwithstanding the fact that the other conditions are favorable for the growth of deep-rooted plants. The effect of close grazing on land occupied by the sand-hills mixed association (Pl. V, fig. 1), which often results in establishing a pure short-grass vegetation between the plants of sand sage, offers a most interesting example of this condition. The sage, which is not eaten, develops into large bushes, owing, doubtless, to the fact that it has no competitors for the water in the deeper layers of the soil. The short grasses also grow well on such land, since the taller grasses are kept down by grazing and can not displace the short grasses by overtopping them.

CROP PRODUCTION ON LAND CHARACTERIZED BY DIFFERENT TYPES OF VEGETATION.

CROP PRODUCTION ON SHORT-GRASS LAND.

PHYSICAL CONDITIONS OF CULTIVATED SHORT-GRASS LAND.

The physical conditions indicated by the presence of short grasses have already been discussed on pages 27 to 40. The water supply available for the plant is greatest in June and rapidly decreases in July, August, and September. The native plants, almost without exception, require only a short growing season. In eastern Colorado land characterized by short-grass vegetation is a loam which will easily take up 25 per cent of the water after a rain. The water penetrates slowly, and as a result of the ability of the soil to hold a high

percentage moisture is usually confined to the upper foot or two of soil. Wherever the land is kept free from vegetation, as in summer tillage without crop, loss of water is greatly retarded and water may be conserved for a fall crop.

WATER PENETRATION.

Measurements were made to determine the comparative penetration and run-off from cultivated land and from the native sod, care being taken to avoid low places or places where there was a perceptible slope.[a]

On September 3, after a rainfall of 1.12 inches, very careful measurements were made at the Akron Dry-Land Experiment Farm, on 6 corn plats, 1 kafir plat, and 1 summer-tilled plat. The corn plats were all well cultivated and had received various treatments previous to spring planting to corn. The conditions represented a wide range of soil management and should, therefore, have given good averages. Each measurement was based upon three carefully selected samples which were chosen in places of average water penetration as shown by the depth to which the dark color of the moist soil extended. This rain was of a torrential character and conditions were most favorable for a high rate of run-off. The run-off at the base station in the short-grass land, where the records of soil-moisture content were taken twice daily throughout the season, was the greatest recorded during the whole period. The comparative results are given in Table X.

TABLE X.—*Penetration and run-off for short-grass sod and cultivated land at Akron, Colo., as a result of a 1.12-inch rain, September 3, 1909.*

Description of land.	Penetration.	Run-off.
	Per cent.	*Per cent.*
Short-grass sod at base station	45	55
Average for 8 cultivated plats	51	49

From these results, as well as from those recorded in another publication,[b] it is evident that run-off is a factor of great importance.

The data here given show that the run-off on cultivated land was very great, in fact, almost as great as on the short-grass sod.

As a result of the heavy rain of 2.39 inches on July 7, the comparative data following were obtained.

[a] The penetration and run-off on land covered with short-grass vegetation are discussed in detail on p. 34.

[b] Briggs, L. J., and Belz, J. O. Dry Farming in Relation to Rainfall and Evaporation. Bulletin 188, Bureau of Plant Industry, U. S. Dept. of Agriculture, 1910, p. 15.

TABLE XI.—*Penetration and run-off for short-grass sod and summer-tilled plat, at Akron, Colo., as a result of a 2.39-inch rain July 7, 1909.*

Description of land.	Penetration.	Run-off.
	Per cent.	*Per cent.*
Short-grass sod at base station	86	14
Summer-tilled plat	48	52

This high percentage of run-off from summer-tilled land accords with the results of previous measurements.[a] Many observations in the field show that the penetration of rain water into a dust mulch, such as is often maintained on a summer-tilled field, is very slow, and that this mulch is almost as effective a preventive of water penetration as of evaporation. On the other hand, observations of the penetration on newly plowed sod and on lumpy, cultivated land show that when the surface is in a rough condition water enters rapidly. It is desirable, especially during the rainy season, to have the soil in such condition as to prevent run-off as far as possible, and to develop a dust mulch only when the soil is already well supplied with water.

BEHAVIOR OF CROP PLANTS.

Because of the fertility of the soil, cultivated crops on short-grass land usually produce a luxuriant growth in the spring and early summer. The water supply, although high enough in percentage, does not extend to any considerable depth and the crop is in very much the same condition as that of potted plants where, although the water supply is sufficient temporarily, it is soon exhausted by rapid growth and the plant is suddenly left with no reserve. The very rapidity and luxuriance of the early growth exhaust the water supply all the more rapidly, and the fact that the water is limited to a shallow surface layer of soil means that loss by direct evaporation is relatively high. During the latter part of July conditions are almost sure to occur which will cause a sudden drying up of the crop. This condition takes place so suddenly that it is practically impossible for any crop to adjust itself rapidly enough to meet this change. Corn is especially liable to be destroyed at this critical period, for it possesses little ability to recover after drought. Wheat crops, particularly the fall wheats, may be ripened before the period of drought comes on, but this does not always happen, and in especially unfavorable years even the small grains will be an entire failure. On the other hand,

[a] Briggs and Belz, op. cit., p. 15. The comparatively low percentage of run-off at the base station has already been discussed. (See p. 34.)

during wet years or years in which a moderate rainfall is unusually well distributed, crop production on short-grass land is greater than on any other type of land in eastern Colorado.

The frequent failures of crops on short-grass land are largely due to lack of sufficient rainfall or to its unequal distribution. Another reason is the fact that during torrential rains by no means all of the rainfall is stored in the soil, a great amount running off, while that which enters the soil remains near the surface and is rapidly lost by evaporation. A further point of importance is that because of the abundance of plant food the crop often grows too luxuriantly in the beginning and consequently uses up at too early a period in its growth the moisture which should have sufficed for the entire season.[a] Under these conditions a field of wheat which produces a good stand of straw may produce no grain, the excessive growth of straw having exhausted the water supply before the grain could ripen. The same is true of other crops, especially corn, which often dries out just at the period of earing. In this connection it is interesting to note that in this region when land is manured the resulting stimulation of growth almost always exhausts the water supply too rapidly. Hence a general impression prevails throughout the Great Plains region, based on actual experience, that manure will cause a crop to burn up; and it is, therefore, only rarely used. These facts make it necessary that the importance of thin seeding be emphasized. Where too many seeds are planted the crop uses up the total water supply before any of the plants mature. Thin planting, on the other hand, leaves a greater water supply for each individual plant. These facts also indicate that dwarf strains are better adapted to short-grass land than the larger and more luxuriant varieties.

Reference to the rainfall records for eastern Colorado (p. 28) will show that during average years the water supply decreases rapidly from July to November. The increased heat in July and August makes this a period of the year when drought is to be expected. The natural plant cover consists chiefly of species that complete their growth by the middle of July. These conditions of climate and soil, illustrated by the behavior of the native vegetation, show that short-grass land is best adapted to what might be termed "early-season crops"—crops which mature early in July. The production of later crops during average years is more or less uncertain because of the tendency for drought to occur after the middle of summer. Among the most successful later crops are sorgo, milo, etc.,

[a] See Chilcott, E. C., "A Study of Cultivation Methods and Crop Rotations for the Great Plains Area," Bulletin 187, Bureau of Plant Industry, U. S. Dept. of Agriculture, 1910, p. 19.

which by their slow growth during the early season conserve the soil moisture and on this account are enabled to continue growth longer than other crops which rapidly exhaust the soil moisture.

Under natural conditions short-grass land is not at all adapted to deep-rooted crops, and clean cultivation is required to establish conditions favorable for such plants. Tillage on short-grass land always produces more favorable water relations by conserving the moisture which enters the soil.

Many timber claims are found in eastern Colorado, but few of them occur on short-grass land. Yet in some places trees have done surprisingly well on such land. While these trees grow on land which was previously covered with the short grasses, the land on which the trees stand now produces wire-grass, as a result of the breaking done when the trees were planted. On this hard type of land the most successful trees seem to be the ash and the box elder, although many other species, especially the elm, hackberry, and honey locust, have grown fairly well.

With clean cultivation and with the trees set far apart, orchards of apple, plum, cherry, pear, and peach trees have been established in several places. The most successful tree growth, however, occurs in land where wire-grass or Psoralea, or both, are rather abundantly mixed with the short grasses. Such trees as willow and cottonwood are not at all adapted to the conditions existing on short-grass land.

Under conditions such as these there seems little to justify the assumption that alfalfa will last for many years on short-grass land, even if a stand can be secured. It is a very deep-rooted plant and not at all adapted to the conditions above described. That water supply is the principal limiting factor should always be borne in mind in considering crop production in this region. A field of rapidly growing alfalfa such as may be seen in irrigated sections would exhaust the total water supply of the soil in a few days. Yet it is possible that alfalfa, when not too thickly seeded or, preferably, planted in rows or hills with intertillage, can be made a profitable crop on short-grass land.

The impression that a very large yield can be obtained provided especially adapted crop plants be grown also seems unfounded, for with the limited water supply even the native plants and weeds never produce a great amount of dry matter in a single season (p. 81). The best estimates obtainable as to the amount of water required to produce a pound of dry matter make it probable that with the average seasonal rainfall of eastern Colorado it would be impossible to produce more than 3 tons per acre, even if no water were evaporated directly from the soil and there were no run-off.

CROP PRODUCTION ON WIRE-GRASS LAND.

PHYSICAL CONDITIONS OF CULTIVATED WIRE-GRASS LAND.

The physical conditions on wire-grass land (p. 50) are very different from those of short-grass land (p. 27). The soil, being of a much lighter texture, absorbs practically all the rain that falls upon it and permits the moisture to penetrate to greater depths. Consequently there is a bed of moist soil extending to a depth of several feet. The presence in the native vegetation of many deep-rooted plants indicates this condition. Under cultivation it is probable that water penetrates still more easily than under natural conditions. Furthermore, the loss of water by evaporation is retarded to a very great extent by cultivation. As a result we find here a condition very favorable for the production of crops either shallow or deep-rooted.

Since water is distributed to considerable depths in this type of soil, the exhaustion of the water supply in the immediate vicinity of the roots is not necessarily fatal to the plant, for there is a large area of moist soil into which roots can penetrate or from which water can move slowly to where it is within reach of the root systems, and this area serves as a reserve in time of drought. The loss of water by evaporation after a rain is not so great on wire-grass land as on short-grass land and the conditions for the conservation of the water supply through the whole season are much better.

BEHAVIOR OF CROP PLANTS.

Taking one year with another, wire-grass land is the best in the region for agricultural purposes. The yield in wet years is almost equal to that of the short-grass land and during the average year it is much better. Often when crops fail entirely on short-grass land wire-grass land will produce good crops. The conditions on land of this type are such as to favor deep-rooted crop plants. It is believed that alfalfa, especially if planted in rows or hills and not too close together, will here find excellent conditions for its growth.

Successful tree claims are more numerous on this type of land than on land of any other type. Among the species that succeed best are the elm, ash, box elder, black locust, and honey locust. The finest grove of trees seen by the writer in this portion of the Great Plains was on this type of land at Cope, Colo. Cottonwood and poplar, as well as a great variety of fruit trees, were growing successfully in this grove. There is a possibility that at this place the trees are subirrigated by water that seeps down from the sand hills, yet this seems unlikely, for during the latter part of the summer of 1909 many of the trees in this plantation, especially those which were in competition with the grasses, suffered so severely from drought that their

foliage was badly wilted. If subirrigation were taking place, this would hardly have occurred, for many of the trees in places known to have no subirrigation were in better condition, although subjected to the same drought.

In general, it may be stated that on wire-grass land the water penetrates to a considerable depth and that the conditions are very favorable for the development of deep-rooted plants. The effect of cultivation on moisture conservation is not so great as on short-grass land, but is still rather marked. The degree to which the soil texture favors the penetration and conservation of water makes this land the best type for agricultural purposes found in eastern Colorado. Under the same climatic conditions crops will mature easily on this type of land when on short-grass land they are entirely burned.

CROP PRODUCTION ON BUNCH-GRASS LAND.

PHYSICAL CONDITIONS OF CULTIVATED BUNCH-GRASS LAND.

The physical conditions indicated by bunch-grass vegetation (p. 55) are those most favorable for the growth of deep-rooted plants. In eastern Colorado this vegetation indicates a sandy soil in which water penetrates very readily and to great depths. The cultivation of this soil does not materially facilitate water penetration nor diminish the rate of water loss. We have under natural conditions a water relation which is most favorable for the growth of plants (Pl. IV, fig. 2) with deep and extensive root systems.

BEHAVIOR OF CROP PLANTS.

During wet years the ease with which water percolates makes it practically impossible for the soil to become too moist for the best growth conditions. During dry years growth is slow on this type of land, and as a consequence the water is only slowly exhausted by the plants. Because of the great depths to which water penetrates and is stored in the soil, plants are able to continue growth during a long period of drought by the gradual extension of their root systems. Under the same climatic conditions bunch-grass land can produce a fair crop when water is entirely lacking in short-grass land. In fact, the bunch-grass land during excessive drought is the best type for crop production, but during average years it is considerably inferior to wire-grass land, largely because the latter is richer in plant food. In a series of pot experiments, soil from short-grass land produced much the best growth, wire-grass land ranked next, bunch-grass land next, soil from the sand-hills mixed association next, while soil from the blow-out association produced the least growth. This is directly in accordance with the production of crops under field conditions when each type of soil is well supplied with water.

Bunch-grass land has the further disadvantage of being liable to blow badly. Hence very little attempt has been made to utilize this land for small-grain crops. The most successful crops have been corn, sorgo, milo, etc.

In eastern Colorado land of this type and that of the wire-grass type is often referred to as "corn land," since by far the greater yield of this crop is produced on farms which are on either bunch-grass or wire-grass land. During the falls of 1907 and of 1908 many good fields of corn were seen on bunch-grass and wire-grass land, while on the adjacent short-grass land the crop was an entire failure.

Trees of many different kinds are commonly grown on bunch-grass land. The cottonwood, willow, Carolina poplar, soft or silver maple, walnut, catalpa, ash, elm, box elder, honey locust, black locust, cherry, apple, plum, Russian mulberry, etc., make a good growth on land of this type, and even on land marked by the sand-hills mixed vegetation (p. 58), and occasionally by the blow-out type (p. 60 and Pl. VI, fig. 1) of vegetation. Conditions on bunch-grass land are favorable for deep-rooted crops, such as trees and alfalfa. Very successful fields of alfalfa are here and there found, especially where it has been seeded in rows and where other plants are not allowed to compete with it for the soil water.

PRECAUTIONS NECESSARY IN HANDLING BUNCH-GRASS LAND.

Ordinary moisture-conservation methods of tillage should never be practiced on bunch-grass land, since nothing is to be gained and there is every chance of loss due to blowing. As a result of many observations in the field, the following methods are suggested:

(1) The land should be laid out in long narrow fields running east and west.[a]

(2) The crops should be so arranged that two adjacent fields are not prepared for seeding at the same time and the soil in both thus left without protection.

(3) Because of the value for hay of the natural growth of grasses occasional or even alternate fields may be left undisturbed for this purpose.

(4) By proper care in arranging the crops those which do not afford a sufficient cover to prevent the soil from blowing can be protected by adjacent crops which do prevent soil movement.

(5) When practicable, as much of the straw or stubble should be left on the field as will be necessary to prevent blowing during winter and early spring.

[a] As indicated by the blow-outs the winds which do the most damage are from a little west of north and a little east of south, hence approximately at right angles to narrow fields running east and west.

(6) Since cultivation does not noticeably increase water conservation, only such cultivation should be done as is necessary to keep down weeds.

(7) When practicable, cultivation should be done only when the surface soil is damp.

(8) If the soil has begun to blow, cultivation deep enough to bring moist soil to the surface will often check it.

(9) Care should be taken to avoid breaking the native sod on crests or hilltops.

(10) Corn, sorgo, milo, and deep-rooted crops, especially perennials, such as trees and alfalfa, should be tried.

A COMPARISON OF THE CONDITIONS INDICATED BY SHORT-GRASS, WIRE-GRASS, AND BUNCH-GRASS VEGETATION.

THE SOIL-MOISTURE RELATIONS INDICATED.

In comparing the conditions found on short-grass, wire-grass, and bunch-grass land, respectively, in the limited area especially considered here, we find that they are largely expressed in the different water relations of the different soils. The rates of water penetration as measured on these three types of land under the same climatic conditions during the summer of 1909, and also comparisons of typical samples of these soils as to other water relations—moisture equivalent and nonavailable soil moisture for Kubanka wheat—are given in Table XII.

TABLE XII.—*Comparison of water relations of short-grass, wire-grass, and bunch-grass land.* [a]

Item of comparison.	Short-grass land.	Wire-grass land.	Bunch-grass land.
Time required for one-half inch of water to penetrate.....seconds..	540	150	40
Moisture equivalent.....per cent..	18.1	9.7	4.7
Nonavailable moisture for Kubanka wheat.....do....	9.6	4.8	2.6

[a] See footnote, p. 18, for a definition of the terms "moisture equivalent" and "nonavailable moisture." It will be noted that the nonavailable water content bears a practically constant ratio to the moisture equivalent for these three types of soil. This relationship has been under investigation during the past two years by Dr. L. J. Briggs and the writer, and will be fully discussed in a publication now in preparation.

Since these soils weigh approximately 84, 93, and 96 pounds, respectively, per cubic foot, we can estimate the depth of penetration of any given amount of rainfall, provided we know the water content of the soil before and after the rain. We may assume, for the sake of illustration, that the water content of the soil before the rain is the nonavailable moisture for Kubanka wheat, and after a rain that the water content is equal to the moisture equivalent. The depth to which water would penetrate in the different soils under these conditions,

provided none were lost by run-off or immediate evaporation, is shown in Table XIII.

TABLE XIII.—*Estimated depth of water penetration, assuming that the water content of the soil to the depth of penetration is raised by the added moisture from the nonavailable moisture to the moisture equivalent.*

As a result of—	Depth of penetration in inches.		
	Short-grass land.	Wire-grass land.	Bunch-grass land.
One inch of rain	8.7	13.7	30.9
The average seasonal rainfall, April to July, 10.35 inches	90	142	320

Differences in the depth of moisture penetration are to a great extent the causes of the differences in the ability of crops to resist drought on land of the different types. Where the moisture is held near the surface it is not only more readily lost by direct evaporation but can be rapidly exhausted by the plants, whose roots reach to every part of the moist layer of the soil. Where the water is distributed to greater depths it is not only less readily lost but can not be exhausted so quickly by growing plants.

It should be noted that streams originating in the sand hills are permanent and do not dry up during periods of drought. This indicates that water is lost by percolating beyond the reach of the plant roots. However, the amount which is lost in this way is probably almost negligible as compared with that dissipated by evaporation and transpiration.

In this region the soils are often very dry in the fall of the year and continue so until early spring. From repeated measurements the data in the first column of figures of Table XIV are given as the approximate water content of the top foot of soil at the end of the dry season just before the spring rains begin.

It will be seen from the figures in Table XII and the first column of figures in Table XIV that something more than the quantity of water shown in the three right-hand columns of Table XIV must be added to each soil before any will become available for the plant.

TABLE XIV.—*Water status at end of dry season for three kinds of soil.*

Kind of soil.	Percentage of water present in surface foot of soil.	Maximum percentage and quantities of water which can be added before any will become available to the plant.		
		Percentage.	Pounds of water per cubic foot of soil.	Inches of water per foot of soil in depth.
Short-grass land	5.0	4.6	3.86	0.74
Wire-grass land	2.7	2.1	1.95	.37
Bunch-grass land	1.3	1.3	1.24	.24

From the above data it is evident that in this region of deficient rainfall the lighter soil offers a more favorable moisture condition than does the heavier soil, even when an equal amount of water penetrates the two soils. When we consider that the run-off on the heavy land is very great and that the rate of penetration is many times less rapid than on the lighter land, the superiority of the latter becomes still more evident.[a]

THE SOIL FERTILITY INDICATED.

Observations in the field as well as pot cultures show that when water is supplied in sufficient quantity short-grass land is most productive, the next in order being wire-grass, then bunch-grass, sandhills mixed, and blow-out land, in the order named; but under ordinary conditions in the field, where the water supply is usually the limiting factor, the order of productivity is by no means that given above, for during dry years bunch-grass land and wire-grass land are much more productive than short-grass land.

Of interest in this connection is the probable duration of the fertility of the soils marked by the different plant associations. Hilgard (Soils, 1906, p. 86) states that in arid and semiarid regions sand is not to be regarded as inferior to other soils in fertility and that there is no reason to suppose that its productiveness is not as lasting as that of the "strong clay soils of the humid regions." The soil, even in the bunch-grass areas, is often dark in color, owing to the presence of a certain amount of humus, and contains a high percentage of the mineral material found in the original rock. In choosing land for farming it would be well to give some attention to the color of the sand, avoiding the lighter colored sand that is commonly found where the blow-out association occurs.

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[a] In a region such as the Great Plains where the rainfall comes during the growing season, the superiority of light over heavy land is probably much greater than in regions of winter rainfall. As a reservoir, the heavy land will hold much more water per cubic foot than light land. Winter rain which enters the soil can be protected by a dust mulch and held in a heavy soil for a long period. J. Widtsoe (The Present Status of Arid Farming in the Great Basin, Official Proceedings of the Dry-Land Congress, 1907, p. 134) states that in Utah "It matters little whether the soil is a sand, a clay, or a loam." But even in this region of winter rainfall the most successful dry farming was originally done on sandy soil. Powell (Report of the Lands of the Arid Region of the United States, with a more detailed account of the lands of Utah, Department of the Interior, 1879, p. 78), in discussing the "Sand Ridge," "south of Ogden and east of Salt Lake," states that "In these localities, and so far as I am aware, in all others where dry land has been successfully farmed, the soil is sandy, and this appears to be an essential condition." In the Great Plains region the summer rainfall makes conditions much more favorable on the lighter land. The condition is very well expressed by Marguerite R. Fink ("Dry Farming," A Homesteader, Official Proceedings Third Dry-Farming Congress, 1909, p. 237): "By experiment we find that clay land will give a luxuriant growth, but it will not ripen, so sandy loam or even a distinctly sandy soil is to be preferred."

AMOUNT OF NATIVE GROWTH PRODUCED.

The geographical distribution of the plant associations and the amount of native growth produced shows that as we pass from the prairie region westward to the more arid region sand becomes relatively a better and better substratum for plants as compared with the heavier soil types. (See pp. 11, 12, and 24.) The bunch-grass association, which produces the largest quantity of dry matter and which in eastern Kansas is able to maintain itself on loam land, is limited largely to the sand in eastern Colorado. The wire-grass association, which succeeds on a loam soil in central Kansas, is found on sandy loam in eastern Colorado. This distribution of the native vegetation in eastern Colorado indicates most clearly that the conditions for growth are more uniformly good on sand than on hard lands. The production of dry matter by the native plant cover varies greatly from year to year. Measurements on August 23, 1909, of the total dry matter, based on croppings of typical square-yard areas and computed in pounds per acre for the sake of convenience in comparison, are as follows: Short-grass land (ordinary cover), 116 pounds; short-grass land (exceptionally close cover), 400 pounds; bunch-grass land (ordinary cover), 840 pounds.[a]

SOIL BLOWING.

It should be noted that in land characterized by the bunch-grass and the sand-hills mixed associations the chief difficulty in producing crops results from the blowing of the soil. The wind by moving the sand not only destroys the young growing crop, but occasionally removes the entire surface layer of the soil. Under natural conditions, where the native sod is undisturbed, this unfavorable condition does not play a part. Consequently, although sand land may produce a much heavier yield of native growth, it does not necessarily follow that it will become proportionately better farming land.

MOISTURE RELATIONS AND CROP PRODUCTION ON HEAVY AND ON LIGHT LANDS.

The physical data given in tables XII to XIV, inclusive, confirm the observations based on the growth of native plants as well as of cultivated crops, that in a region of deficient water supply the lighter soil presents safer conditions for crop production during average years than does the heavier soil. This is largely due to the

[a] From the bunch-grass sample all dead stems, which amounted to an additional 1,100 pounds per acre, were removed. Many of these dry stems were produced in former years and were removed in order to reduce the weight to that actually produced during the season when the cropping was made. The short-grass samples contained all of the plant material above the surface of the soil, so that the above comparison is really too favorable to land of this type.

differences in moisture relations, but must be partly explained as due to the fact that cultivated plants do not grow so large nor use so much water on sand as on the hard land, and they are, on this account, much more likely to mature. The cultivation of hard land can not wholly overcome these differences. The loosening up due to cultivation will increase rather than decrease the water-holding capacity of the upper soil layer. It can, therefore, increase the depth of water penetration and bring about the storing of a greater amount of soil moisture in the lower depths only by reducing run-off, lowering the rate of evaporation, and preventing plant growth. On heavy land crop plants will be stimulated to rapid growth by every rainfall that is sufficient to furnish a good supply of water. But this supply will be limited to the shallow layer of the soil that is occupied by the roots. Drought will do far more damage under these conditions than it would to a crop on lighter land, which has a much deeper layer of moist soil from which to draw its water supply and on which the growth is less luxuriant.

SUMMARY.

(1) The natural vegetation is largely used to indicate the agricultural capabilities of land, but there are many possibilities of error, as this indicator is ordinarily employed.

(2) The object of the present publication is to show how this indicator may be employed accurately for the ready classification of new land.

(3) By indicating clearly the environmental conditions which prevail the native vegetation is of great value, not only in the classification of land, but also as an indicator of the kind of crop and methods of culture that are most likely to succeed under the given conditions.

(4) Differences in the vegetation can be used to indicate changes in one factor of the environment only when all the other factors remain unchanged.

(5) Correlations with soil moisture are usually more easily established than with any other one factor, since it is through this factor that rainfall, evaporation, and the physical character of the soil chiefly affect the plant.

(6) Since plant growth is the ultimate measure of the suitability of the physical environment, the character, growth, and condition of the native vegetation are the best possible indicators of conditions favorable or unfavorable to crop production on land where crops have not yet been produced.

(7) The entire plant cover is a better indicator than the presence or condition of a single species, since in it we have a record which is

as stable as the most stable species and as sensitive as the most exacting plant.

(8) The results described in the present paper are based upon a detailed study of the natural vegetation of Washington and Yuma counties, in eastern Colorado, and upon more general studies made throughout the Great Plains region.

(9) The chief plant associations of eastern Colorado which indicate land of agricultural value are the grama–buffalo-grass association and the wire-grass association (both of which belong to the short-grass formation) and the bunch-grass association and the sand-hills mixed association (both of which belong to the prairie-grass formation).

(10) The chief vegetation types of eastern Colorado which indicate nonagricultural land are the lichen formation, the Gutierrezia-Artemisia association of the short-grass formation, and the blow-out association of the prairie-grass formation.

(11) Of the associations indicating land of agricultural value in eastern Colorado, the grama–buffalo-grass association is most extensive, occupying the greater part of the hard land. The bunch-grass and the sand-hills mixed associations occur only in the sand-hill regions, while the wire-grass association occurs on land of intermediate character.

(12) In eastern Colorado the rainfall records show that the average monthly rainfall is greatest during the period April to August. The increased heat in July and August makes it almost certain that drought will occur in these months. September and the later fall months have normally very little rainfall, and fall-sown grain often fails to germinate unless planted on land in which water from rains earlier in the season has been conserved by summer tillage.

(13) Measurements show that from grama–buffalo-grass land a great amount of water runs off and does not enter the soil.

(14) Soil-moisture determinations in this type of land show that even during periods of more than normal rainfall available soil moisture is limited to a few inches of the surface soil.

(15) On this account the vegetation is composed largely of short grasses which have a great number of roots limited to the surface foot or two of the soil.

(16) Moisture, even in the surface few inches of the soil, is often lacking except during a few weeks in spring and early summer. The short grasses have a comparatively short growing season.

(17) Deep-rooted species are shut out by the lack of soil moisture in the deeper layers of the soil and later-season plants are excluded because available moisture is usually lacking, even in the surface layers, during late summer and autumn.

(18) An open cover of the short grasses indicates conditions less favorable for crop production than a close cover.

(19) The presence of deeper rooted plants mingled with the short-grass vegetation indicates better conditions for crop production than those found where the cover is purely of the short grasses.

(20) The occurrence among the short grasses of plants characteristic of the associations which indicate land without agricultural value suggests a less favorable condition for crop production than where short grasses only are found.

(21) The presence of the wire-grass association indicates that there is a considerable amount of water in the deeper layers of the soil, owing to the lesser run-off and to the fact that the lighter soil permits deeper penetration.

(22) Conditions indicated by the wire-grass association are favorable for both shallow-rooted and deep-rooted plants and for a considerably longer period of growth than those indicated by the grama–buffalo-grass association.

(23) The bunch-grass association indicates a soil that is moist to a considerable depth. Here conditions are more favorable for deep-rooted and late-season plants than in land characterized by either the short-grass or the wire-grass vegetation.

(24) The sand-hills mixed association indicates conditions very similar to those of the bunch-grass association, but rather less favorable, as shown by the smaller amount of plant growth.

(25) The short-grass vegetation represents the final stage in a succession which may begin with the lichen formation and pass through the Gutierrezia-Artemisia association. Or the succession may begin with the blow-out association and pass through the sand-hills mixed and the bunch-grass associations and (by the aid of fires and grazing) through the wire-grass association to a pure short-grass vegetation.

(26) When short-grass land is left without cultivation after breaking it will be revegetated by either the wire-grass or the Gutierrezia-Artemisia association, depending upon the physical conditions.

(27) The vegetation which establishes itself after wire-grass is turned under is that which is naturally characteristic of a lighter soil.

(28) When the native sod of the bunch-grass or the sand-hills mixed associations is broken, a blow-out may result. Usually, however, the original vegetation is soon reestablished.

(29) When the vegetation of any of the plant associations is destroyed by breaking and the land is then abandoned the land will be reoccupied (after a weed stage) by vegetation that is characteristic both of a lighter type of soil and of an earlier stage in the natural

succession. These successions are the result of changes in the physical conditions brought about largely as a result of the destruction and reestablishment of the plant cover itself.

(30) The taller, deeper rooted plants are easily shut out by the shallow-rooted short grasses when the water that falls as rain is not sufficient to penetrate beyond the layer of soil occupied by the roots of the short grasses before it can be absorbed by them.

(31) Where water can readily penetrate below the depth ordinarily reached by the roots of the short grasses the conditions are favorable to the growth of deeper rooted and taller species, which shut out the short grasses by overshading them. This increased penetration of water may be due either to greater rainfall or to lighter soil texture.

(32) When well supplied with water short-grass land is the most productive under cultivation of any in eastern Colorado. During drought, however, crops suffer on this land sooner than on any other type.

(33) During exceptionally dry years bunch-grass land produces the best crops of any in eastern Colorado, but during wet years its production is surpassed by that of all others except the land characterized by the sand-hills mixed association. The soil under both of these types of vegetation is likely to blow badly.

(34) Wire-grass land represents a safe intermediate condition where in years of ample rainfall crop production compares not unfavorably with that on short-grass land and where, even during dry years, a fair crop can often be produced.

(35) One of the chief reasons for the superiority of light land over heavy land in eastern Colorado is that crop growth is rapid on the latter and that the total available supply of soil water lies near the plant roots, the crops, therefore, being in somewhat the same condition as potted plants. These conditions favor a rapid exhaustion of soil moisture and, consequently, bring about sudden drought. On the lighter land water is distributed to greater depths, the plant growth is slower, and plants, by gradually increasing their root area, can resist much longer periods of drought.

(36) Investigations of soil conditions, as well as actual observations of crops in the field and studies of the native plant cover, show that as we pass from the prairie westward to the more arid portion of the Great Plains the lighter soils present relatively more favorable moisture conditions and, therefore, conditions more favorable to plant growth than do the heavier types of land.

CONCLUSIONS.

It is believed that the evidence presented in the present paper justifies the conclusion that the character of the natural plant cover can be used as a reliable indicator of the conditions favorable or unfavor-

able for crop production, provided the relations between the vegetation and the environment are correctly interpreted.

On the Great Plains a pure short-grass cover indicates a condition of considerable run-off and of limited water penetration, the available moisture usually being confined during the greater part of the season to the first 2 feet of soil. Under cultivation these conditions are modified chiefly by retarding water loss, thus permitting the water to penetrate deeper into the soil. But the penetration is still so slight that the roots of the comparatively shallow-rooted small grains are usually able to occupy the entire depth of soil where water is stored and in time of drought are in much the same condition as potted plants. The rather rank growth on short-grass land made by crops early in the season also greatly increases loss of water by transpiration from the plants and may be instrumental in causing a total failure when dry weather sets in, although with a less vigorous growth the supply might have been fully adequate to the needs of the crop. The presence of a short-grass cover indicates a growing season that is shortened by the limitation of the water supply. Crops which mature early are therefore more likely to succeed on this type of land than crops that require a longer season. Such land is not at all adapted to deep-rooted crops unless the plants are grown far apart and with adequate intertillage. Summer tillage is often necessary to insure the germination of fall grains.

Wire-grass indicates land into which almost all the rainfall penetrates. Because of the lighter texture of the soil the water is distributed to a greater depth, and on this account the native vegetation is partly composed of deep-rooted plants. Under natural conditions evaporation from the soil is here a much less important factor than on short-grass land. The conditions are such that plant roots can not exhaust the soil water as quickly as on short-grass land. The moisture is distributed to a much greater depth, and when drought threatens plants are able to draw on the reserve found in the lower layers of the soil. On this account periods of drought cause much less damage to vegetation on this type of land than on short-grass land. Crop growth on wire-grass land, even during favorable years, is almost as good as on short-grass land, and during average and dry years much better crops are produced on wire-grass than on short-grass land. The native plant cover indicates a considerably longer growing season than on short-grass land, as well as a much more favorable condition for the production of deep-rooted plants.

On bunch-grass land the soil texture is such as to insure the penetration of practically all the water that falls. Cultivation does not seem to retard water loss to any perceptible extent, except by keeping

down the growth of weeds. Crop growth is much less luxuriant on this land than on short-grass land when well supplied with moisture. This retardation of growth itself aids in conserving the soil water. When periods of drought occur the roots of the plants can draw upon a large mass of soil which is supplied with available moisture and which serves as a storage reservoir for the crop. The result is that crops on this type of land are comparatively seldom burned up or even wilted by periods of drought. The native plants are such as require a very long season of growth and indicate conditions favorable for deep-rooted as well as late-season crops.

Crop failures occur oftenest on short-grass land; least often on bunch-grass land. The largest yields are obtained during favorable years on short-grass land; the smallest on bunch-grass land. During wet years short-grass land is best; during dry years bunch-grass land is best. Wire-grass land represents a safe intermediate condition, for in years of ample rainfall crop production upon it compares not unfavorably with that on short-grass land, and even during dry years a fair crop can often be produced.

Using the native vegetation as an indicator of the capabilities of crop production, we would class the type of land that is characterized by the wire-grass association year in and year out as the most valuable agricultural land in eastern Colorado. With it, or very close to it, should be classed that type of short-grass land which bears a considerable growth of wire-grass or of Psoralea, for the presence of these plants indicates conditions intermediate between those indicated by the typical wire-grass association and those indicated by the typical grama–buffalo-grass association.

Many of the older settlers in eastern Colorado have moved from short-grass land onto wire-grass land, or even onto bunch-grass land, where they claim there is much less likelihood of crop failure; but the newcomer in the region or the speculator almost invariably chooses the hard or short-grass land because it is darker in color and looks more like the soil he has been accustomed to farm successfully in the East. On this account short-grass land brings the highest price and changes hands oftenest, while wire-grass and bunch-grass lands are not so readily sold and bring much less per acre.

PLATES.

DESCRIPTION OF PLATES.

PLATE I. Fig. 1.—A typical view in the grama–buffalo-grass association, Burlington, Colo. A pure short-grass cover, which indicates that available water is limited to the surface layers of the soil and is usually present only during spring and early summer. These conditions are not favorable for long-season or deep-rooted crops. During dry years this land is first to suffer from drought, but during wet years it will produce the largest yields of any type of land in this region. Fig. 2.—A typical view in the wire-grass association, Yuma, Colo. A mat cover of short grasses, together with a number of deep-rooted and taller growing plants, chief among which are wire-grass and Psoralea. This vegetation indicates a longer growing season than the grama–buffalo-grass association, and also that a considerable amount of water penetrates below the root area of the short grasses. Because of the favorable water relations and the facts that the soil does not blow and is very productive when sufficiently supplied with water, wire-grass land is believed to be the best type in this region for general crop production.

PLATE II. Fig. 1.—The Gutierrezia-Artemisia association established as a result of breaking or plowing under the short-grass vegetation, Akron, Colo. At the right the comparatively pure grama–buffalo-grass association is undisturbed. At the left the Gutierrezia-Artemisia association has become established on the breaking which was abandoned about eight years before the photograph was taken. Fig. 2.—The wire-grass association established as a result of breaking or plowing under the short-grass vegetation, Yuma, Colo. At the right the pure grama–buffalo-grass association is undisturbed. At the left the wire-grass association has become established on the breaking which was abandoned eight years before the photograph was taken. The soil at a depth of two feet at the left was moist and in fair condition, while at a similar depth at the right it was dry and cracked open.

PLATE III. Fig. 1.—Psoralea on short-grass land, Yuma, Colo. A dense short-grass cover amid which appears a rather uniformly scattered growth of the taller bush-like plants of *Psoralea tenuiflora*. This type of vegetation indicates a condition where moisture is available at a considerable depth in the soil, and which is therefore more favorable than pure short-grass land for crop production, especially for deeper rooted crops. This type of vegetation indicates conditions somewhat similar to those indicated by the wire-grass association. Fig. 2.—Wire-grass on short-grass land, Vernon, Colo. A rather close cover of the short grasses amid which are scattered clumps of wire-grass. The wire-grass indicates that at least during spring and early summer there is available water in the deeper layers of the soil, and hence a more favorable condition for crop production. This type of vegetation is closely related to the pure wire-grass association, and indicates conditions similar to those indicated by that association.

PLATE IV. Fig. 1.—A typical view in the bunch-grass association, Cope, Colo., a scattered growth of bunch-grass with a variety of other plants occupying the interspaces. This vegetation indicates a soil which is moist to a depth of many feet and a rather long period favorable for plant growth. Large crop yields are never secured on this type of land when under cultivation, but during dry years it will give a better yield than any other type in this region. The chief difficulty with land of this type is that it often blows badly when left unprotected. Fig. 2.—Typical view in the bunch-grass association showing the amount of wild hay produced on land of this type, Yuma, Colo. Hay can not be cut every year from this land, since several years are required for the bunch-grass again to produce a good growth. The value of this hay depends largely on the amount of grama, sand-grass, and big bluestem which it contains.

PLATE V. Fig. 1.—A typical view in the sand-hills mixed association, Wray, Colo.; scattered growth of sand sage with clumps of *Calamovilfa longifolia*, *Andropogon hallii*, grama, and a few plants of bunch-grass. A great variety of species occurs in this association. The vegetation indicates a soil which is moist to a depth of many feet and a rather long period of growth. Large crop yields are never obtained on this type of land when under cultivation, but during dry years it will produce almost as well as bunch-grass land. The danger of the soil blowing is even greater than on bunch-grass land. Fig. 2.—The sand-hills mixed association where closely grazed, Wray, Colo. The plants of sand sage here grow luxuriantly. The spaces between these plants are either occupied by the closely grazed plants of the sand-hills mixed association, or, where the grazing has continued for a long period, by an almost pure stand of grama grass. The conditions for crop production are the same as those on land characterized by the unmodified sand-hills mixed association.

PLATE VI. Fig. 1.—A blow-out as a result of breaking done twenty years before, Yuma, Colo. This land was plowed and planted to trees which have all blown out except a few at the north side. The trees are soft or silver maple and have made good growth with no care or protection from cattle and horses, which eat off all the foliage within their reach. The vegetation in the foreground is chiefly *Psoralea lanceolata*, that in the background *Redfieldia flexuosa*. Fig. 2.—A typical view in the Gutierrezia-Artemisia association, La Junta, Colo. The plants cover only a small part of the surface of the soil. The principal plants here shown are Gutierrezia and grama grass, but a great many species are important in this association. This type of vegetation indicates a soil which contains a great deal of partly disintegrated rock and one not suited to crop production.

FIG. 1.—TYPICAL VIEW IN THE GRAMA-BUFFALO-GRASS ASSOCIATION, BURLINGTON, COLO.

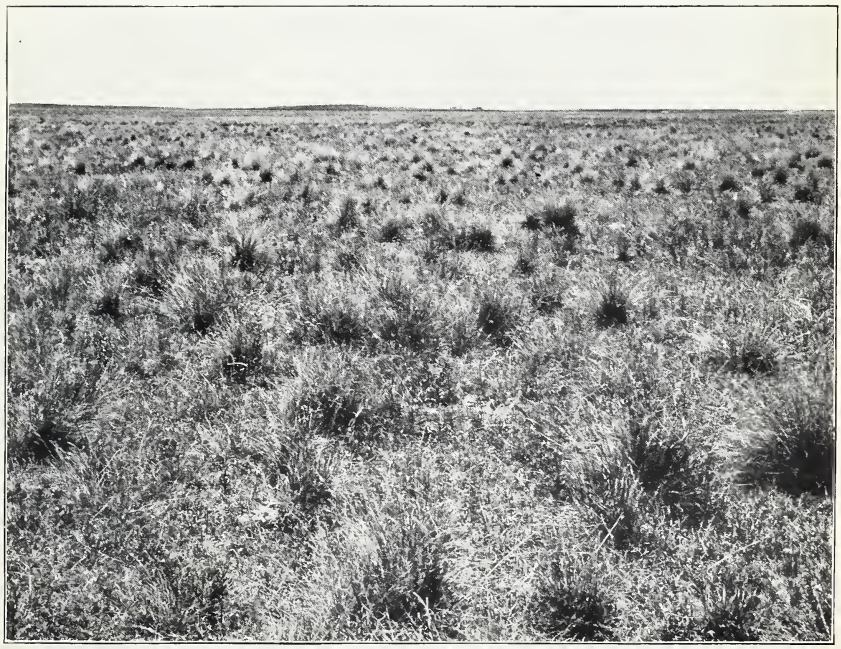

FIG. 2.—TYPICAL VIEW IN THE WIRE-GRASS ASSOCIATION, YUMA, COLO.

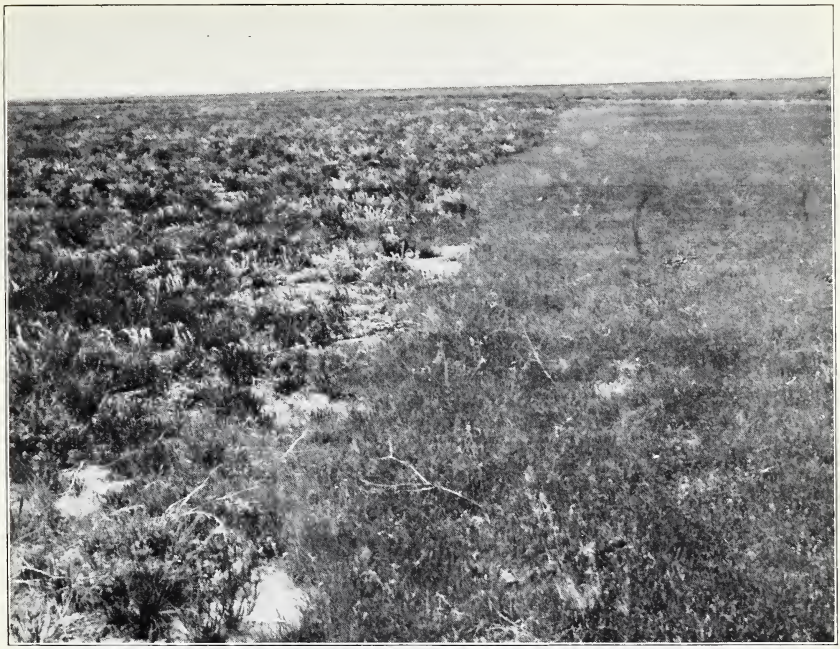

FIG. 1.—THE GUTIERREZIA-ARTEMISIA ASSOCIATION ESTABLISHED AS A RESULT OF BREAKING SHORT-GRASS LAND, AKRON, COLO.

FIG. 2.—THE WIRE-GRASS ASSOCIATION ESTABLISHED AS A RESULT OF BREAKING SHORT-GRASS LAND, YUMA, COLO.

FIG. 1.—PSORALEA ON SHORT-GRASS LAND, YUMA, COLO.

FIG. 2.—WIRE-GRASS ON SHORT-GRASS LAND, VERNON, COLO.

FIG. 1.—TYPICAL VIEW IN THE BUNCH-GRASS ASSOCIATION, COPE, COLO.

FIG. 2.—THE BUNCH-GRASS ASSOCIATION, SHOWING THE AMOUNT OF HAY PRODUCED, YUMA, COLO.

FIG. 1.—TYPICAL VIEW IN THE SAND-HILLS MIXED ASSOCIATION, WRAY, COLO.

FIG. 2.—THE SAND-HILLS MIXED ASSOCIATION WHERE CLOSELY GRAZED, WRAY, COLO.

FIG. 1.—BLOW-OUT AS A RESULT OF BREAKING DONE TWENTY YEARS BEFORE, YUMA, COLO.

FIG. 2.—TYPICAL VIEW IN THE GUTIERREZIA-ARTEMISIA ASSOCIATION, LA JUNTA, COLO.

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